LMSC-A980307
VOLUME III
DECEMBER 14, 1970

imblms

INTEGRATED MEDICAL AND BEHAVIORAL LABORATORY MEASUREMENT SYSTEM

Final Report For
PHASE B.4 PROJECT DEFINITION
(CONTRACT NAS9-10742)

VOLUME III
MEASUREMENT CONSIDERATIONS

LOCKHEED MISSILES & SPACE COMPANY
A GROUP DIVISION OF LOCKHEED AIRCRAFT CORPORATION
SPACE SYSTEMS DIVISION · SUNNYVALE, CALIFORNIA

LMSC-A980307
Volume III
December 14, 1970

FINAL REPORT FOR

INTEGRATED MEDICAL AND BEHAVIORAL LABORATORY MEASUREMENT SYSTEM

(IMBLMS)

Phase B.4 Project Definition

Volume III

MEASUREMENT CONSIDERATIONS

IMBLMS

The National Aeronautics and Space Administration is sponsoring studies to develop an Integrated Medical and Behavioral Laboratory Measurement System. IMBLMS will be a highly flexible, state-of-the-art system, capable of acquiring, displaying, analyzing, and recording a wide variety of medical, biochemical, microbiological, and behavioral measurements and experiments designed to study in detail man's well being and operational capability during long-duration space missions. IMBLMS also includes a comprehensive clinical capability for conducting routine physical examinations and providing treatment in the event of injuries or other medical emergencies.

IMBLMS work stations and peripheral equipment modules are designed for ease of maintenance and adaptability of the measurements and experiments to meet changing requirements, based on the trend analysis of previously collected data and the development of more advanced measurement techniques.

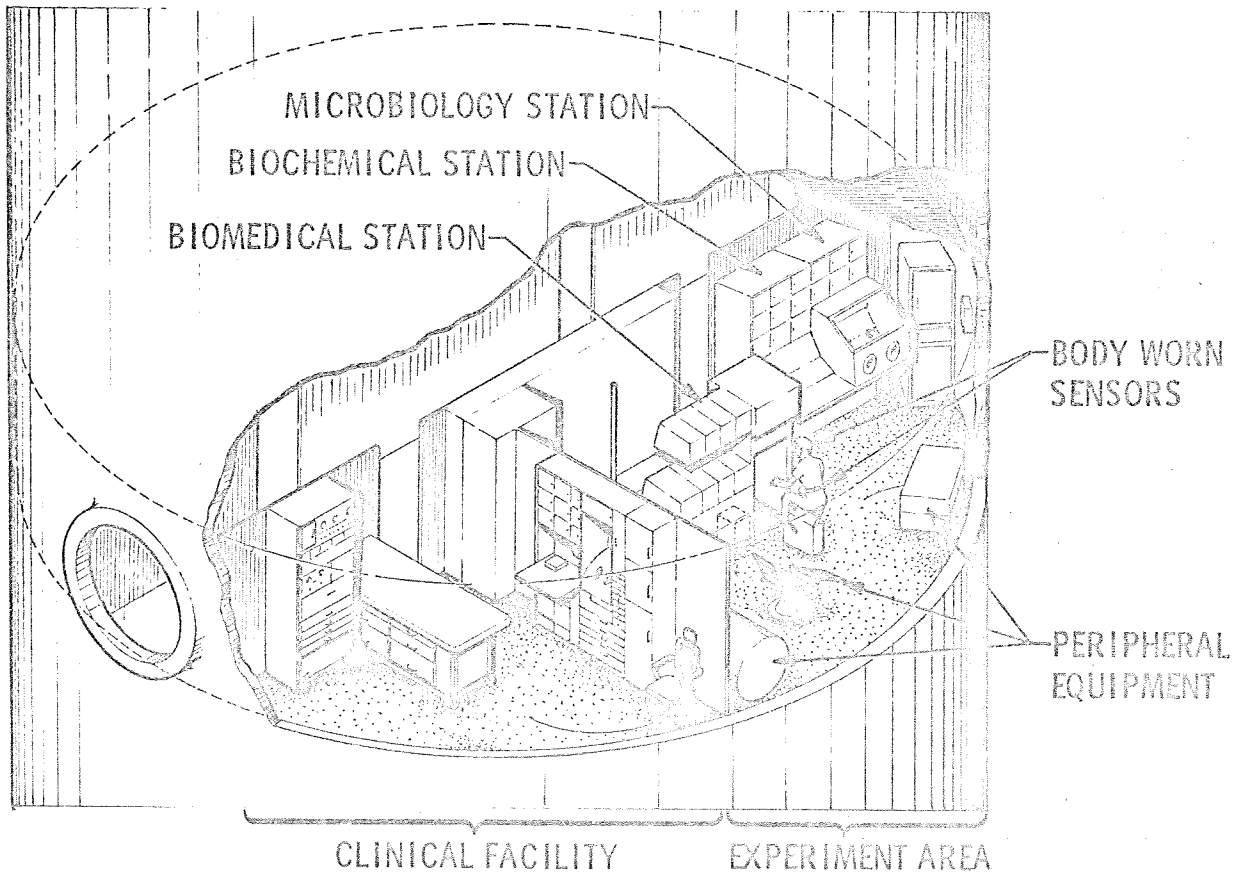
As evolved through several study phases, IMBLMS consists of two major work stations – biomedical/behavioral and biochemical – and a variety of peripheral systems and equipment. Major items of peripheral equipment include a lower body negative pressure device, a bicycle ergometer, and a rotating litter chair. Central to IMBLMS operations is a data management system, which provides for controlling, processing, recording, and transmitting information derived from the various measurements.

The major measurement categories are as follows:

- Neurological and sensory
- Cardiovascular
- Metabolic
- Respiratory
- Microbiological
- Biochemical
- Behavioral
- Clinical

Deployment of IMBLMS will involve the development of baseline data in all measurement areas. Primary emphasis is placed on detection and evaluation of incipient problems that may occur with extended manned spacecraft missions. Flexibility in measurement capabilities, scheduling, and interpretations is essential to an effective program in order to focus on specific findings.

The first flight version of IMBLMS is intended for use on the first Space Station – both as an experiment and as a clinical facility. Because of its compactness and scientific potential, it is also suitable for use in any of the planned manned space vehicles, such as Skylabs or an interplanetary craft. Furthermore, its dual role of scientific experiment and clinical facility makes it a logical candidate for use on lunar bases and, of impressive spinoff value, in earth-based medical facilities.



Page intentionally left blank

Page intentionally left blank

iii & iv

PRECEDING PAGE BLANK NOT FILMED

FOREWORD

This is one of the several documents constituting the Lockheed Missiles & Space Company Final Report for Phase B.4 of the Integrated Medical and Behavioral Laboratory Measurement System Program, which is sponsored by the NASA Manned Spacecraft Center, Contract NAS9-10742.

The report consists of the following volumes:

I	Introduction and Summary	(LMSC-A980305)
II	System Considerations	(LMSC-A980306)
III	Measurement Considerations	(LMSC-A980307)
IV	Preliminary Design	(LMSC-A980308)
V	Mission Operations	(LMSC-A980309)
VI	Flight and Ground Support	(LMSC-A980310)
VII	Program Plans	(LMSC-A980311)
VIII	Specifications and Drawings	(LMSC-A980312)
Appendixes		(LMSC-A981477)
A	Psychomotor Measurements	(LMSC-A980461)
B	Measurement Requirement Data Sheets	(LMSC-A980462)
C	Laboratory Verifications	(LMSC-A980463)
D	Supporting Analyses	(LMSC-A980464)

This volume fulfills the requirements set forth in the Phase B.4 Statement of Work, Exhibit A, Task I, item E.

ABBREVIATIONS

A/D	analog to digital converter
BCG	ballistocardiogram
BMMD	body mass measurement device
BSR	basal skin resistance
CFF	critical flicker (or fusion) frequency
CRT	cathode ray tube
ECG	electrocardiogram
ECLSS	environmental control and life support subsystem
EEG	electroencephalograph
EMG	electromyogram
EOG	electrooculogram
FBB	functional breadboard
GSR	galvanic skin resistance
MEDATA	medical data
PCG	phonocardiogram
pH	measure of hydrogen ion concentration
RBC	red blood cell count
SGOT	serum glutomic-oxalocetic transaminase
SGPT	serum glutomic-pyruric transaminase
SIP	system input panel
SISI	short increment sensitivity index
SMMD	specimen mass measurement device
VbCG	vibrocardiogram
VCG	vectorcardiogram
WBC	white blood cell count
ZPN	impedance pneumogram

CONTENTS

Section 1
INTRODUCTION

In preparation for meeting the overall IMBLMS objective, which is to attain mission goals while safeguarding the physical and mental well being of man during space flights extending from several months to several years, detailed study is necessary to accomplish the following:

(1) Determine the overt and insidious effects of space flight on man.

(2) Determine the time course of such effects.

(3) Establish the specific etiologies and mechanisms through which these effects are mediated.

(4) Develop predictive indices for the onset and severity and, in some cases, the duration of these effects.

(5) Delineate man's tolerance and adaptiveness to these effects.

(6) Develop techniques for preventing or correcting the deleterious effects.

In addition to its highly sophisticated investigative and experimental measurement and analysis capability, IMBLMS must include a comprehensive clinical capability to diagnose and treat a broad spectrum of mishaps, accidents, and diseases that can befall highly trained astronauts and less rugged nonastronauts, who may be onboard as scientific investigators.

To ensure maximum compliance with the measurement requirements set forth in the IMBLMS Phase B.4 Statement of Work and to meet the objectives for the preliminary design of the flight IMBLMS, all measurements and measurement techniques have been extensively reviewed and reappraised on the basis of experience gained with the Phase B.3 functional breadboard. In this systematic evaluation of the individual measurement, factors such as the following were taken into account:

(1) The relative importance of the measurements in determining man's response and performance capabilities on prolonged exposure to space flight conditions

(2) The diagnostic value of the measurements in recognizing and identifying any physiological changes or illness that may occur

(3) The validity of the measurements as possible predictive indices of the astronauts' well being and effectiveness

(4) The feasibility of converting the most current measurement techniques for space flight use in those cases where such techniques showed an increased accuracy, repeatability, and clinical validity, as compared to those included in the FBB

(5) The feasibility of expansion for new measurements

During this analysis, appropriate attention was also given to:

(1) Applicability and adaptability of the measurements for medical research purposes

(2) Integration with other measurements and peripheral equipment

(3) Commonality of equipment

(4) Compatibility with simple (Skylab) and more complex (Space Station) data management systems

(5) Astronaut acceptability and comfort

(6) Crew skill and training requirements

(7) Minimization of measurement preparation time

(8) Operator/subject/equipment interface requirements

The individual physiological, behavioral, and clinical laboratory measurements to be included in the IMBLMS design are summarized in Table 1-1, in which items are coded, per the legend at the end of the table.

Table 1-1

IMBLMS PHASE B.4 MEASUREMENTS

Clinical
- History (MEDATA)
- ● Physical examination
  - General
  - Integument
  - Head and neck
  - Respiratory system
  - Cardiovascular system
  - Gastrointestinal system
  - Genitourinary system
  - Nervous system

Neurological and Sensory
- EEG, EOG, EMG } level-of-consciousness, sleep analysis and clinical
- BSR/GSR
- Agravic perception
- Ocular counterrolling
- Oculogyral illusion
- Angular acceleration threshold
- Visual task with head rotation
- Coriolis sickness suscept.**

Table 1-1 (Cont.)

Neurological and Sensory (cont.)
- Auditory:
  - Absolute threshold
  - Pitch discrimination
  - Temporal acuity
  - ● Speech intelligibility
  - Short increment sensitivity index*
- Visual:
  - Perimetry
  - Color perception
  - Critical fusion frequency
  - Dark adaptation
  - Photostress
  - Brightness threshold
  - Vernier acuity
  - Depth perception
  - ● Horizontal phoria
  - ● Vertical phoria
- Cutaneous sensitivity:
  - Pressure thresholds**
  - Touch threshold*
  - Two-point threshold*
  - Vibration threshold*

Cardiovascular
- ● Clinical and reference ECG
- VCG
- BCG
- PCG/VbCG
- Cardiac output:
  - ZCG
  - VbCG
  - CO_2 – rebreathing
  - (BCG)*
- ● Arterial blood pressure
- Venous blood pressure
- Segmental* plethysmography
- Pulse wave contour
- Pulse wave transit time
- Pulse wave velocity**
- ● Heart rate
- ECG/VCG contourography
- ECG/VCG 1st derivative*
- Polarcardiography*
- ● Electronic stethoscope*

Respiratory
- ● Respiration rate
- Tidal volume
- Minute tidal volume
- Expiratory reserve volume
- Vital capacity
- Timed vital capacity
- Maximum inspiratory flow
- Maximum expiratory flow
- Inspiratory capacity
- Maximum breathing capacity
- Maximum inspiratory pressure*
- Maximum expiratory pressure*
- Airway resistance
- Lung compliance**
- ● $\dot{V}$-V loop display*
- Respiratory dead space
- Functional residual capacity
- Total lung capacity
- O_2 consumption
- CO_2 production
- Respiratory quotient
- Alveolar ventilation
- Alveolar pO_2
- Alveolar pCO_2
- Cardiac Output
- Diffusing capacity**

Laboratory Analysis

Blood:
- ● Hemoglobin
- ● Hematocrit
- pH
- pO_2
- pCO_2
- ● RBC count
- ● WBC count
- ● WBC differential
- Platelet estimation
- Reticulocytes
- RBC mass
- RBC fragility
- ● Bleeding time
- ● Clotting time
- RBC survival
- RBC morphology
- Clot retraction

Table 1-1 (Cont.)

Laboratory Analysis (cont.)

Plasma:
- ● Sodium
- ● Potassium
- ● Chloride
- Calcium
- ● Proteins (total)
- Glucose
- Phosphate
- Plasma volume
- ● SGOT
- ● SGPT
- Alkine phosphatase
- ● Bilirubin
- Protein electrophoresis*
- Alk. phosph. electrophoresis*
- ● CPK*
- LDH isoenzymes*
- Immuno-globulins*
- ● Bun*
- ● Prothrombin time*

Urine:
- Color
- ● Volume
- ● Specific Gravity
- ● Glucose
- ● Protein
- ● Bile
- ● pH
- ● Blood
- ● Sediments
- Acetone bodies
- Protein electrophoresis*
- Calcium
- Phosphate
- Sodium
- Potassium
- Chloride

Feces:
- Mass
- ● Occult blood*

Metabolic
- Body mass
- Specimen mass
- Body Volume
- Total body water

Metabolic (cont.)
- Muscle size
- Muscle strength
- Skin temperature
  - Direct and average
- Skin heat flux*
  - Direct and average
- ● Ear canal (body) temperature
- O_2 consumption and CO_2 production (respiration)
- Balance studies (biochemical)

Behavioral

Psychomotor:
- Fine motor abilities – steadiness
- Continuous control
- Complex motor abilities
- Gross body coordination
- Reaction time
  - Simple
  - Complex

Complex behavior:
- Short-term memory
- Complex perceptual processes
- Mediational processes

Microbiology

Bacteria and Fungi:
- ● Culture
- ● Antibiotic sensitivity
- Stain
- Observe
- Identify
- Photograph
- Transmit

Environmental
- Cabin pressure
- Atmosphere composition
- Temperature
- Relative humidity
- Spacecraft motion
- Noise level
- Radiation level
- Atmospheric particulates*
- Microbial assays*

Legend: ● Clinical measurement
* New measurement or display mode, recommended by LMSC for Phase C
** NASA measurement; not recommended by LMSC

Section 2
NEUROLOGICAL AND CARDIOVASCULAR MEASUREMENTS

Although all measurements can be made on an individual basis, most neurological and cardiovascular measurements yield maximum significance only when the primary parameters are recorded simultaneously with certain secondary or supporting parameters.

Grouping of these measurements into several discrete measurement assemblies is illustrated in Fig. 2-1. A similar but less elaborate grouping concept, which was followed in LMSC's functional breadboard, has proven to be a convenient and rapid method of preparing a subject for a particular measurement or experiment.

It has been suggested that the use of plug-in signal conditioners would give the onboard investigator the flexibility of selecting the measurements in any given experiment according to his own preference. However, the problems encountered with this concept negate its implementation. Some of these problems are discussed in the following paragraph.

The transmission of different physiological parameters over widely different frequency passbands requires a multiplicity of different sampling rates. Although it would be possible, for example, to sample a body temperature channel at a rate of 500 or 1000 samples per second, the sampling of an ECG waveform at a rate of 20 samples per second (the rate for a temperature channel) would result in grossly distorted (and therefore worthless) signals.

In view of the large number of data channels required simultaneously in certain experiments, conversion of all channels at some maximum sampling rate could result in oversaturating the data management system.

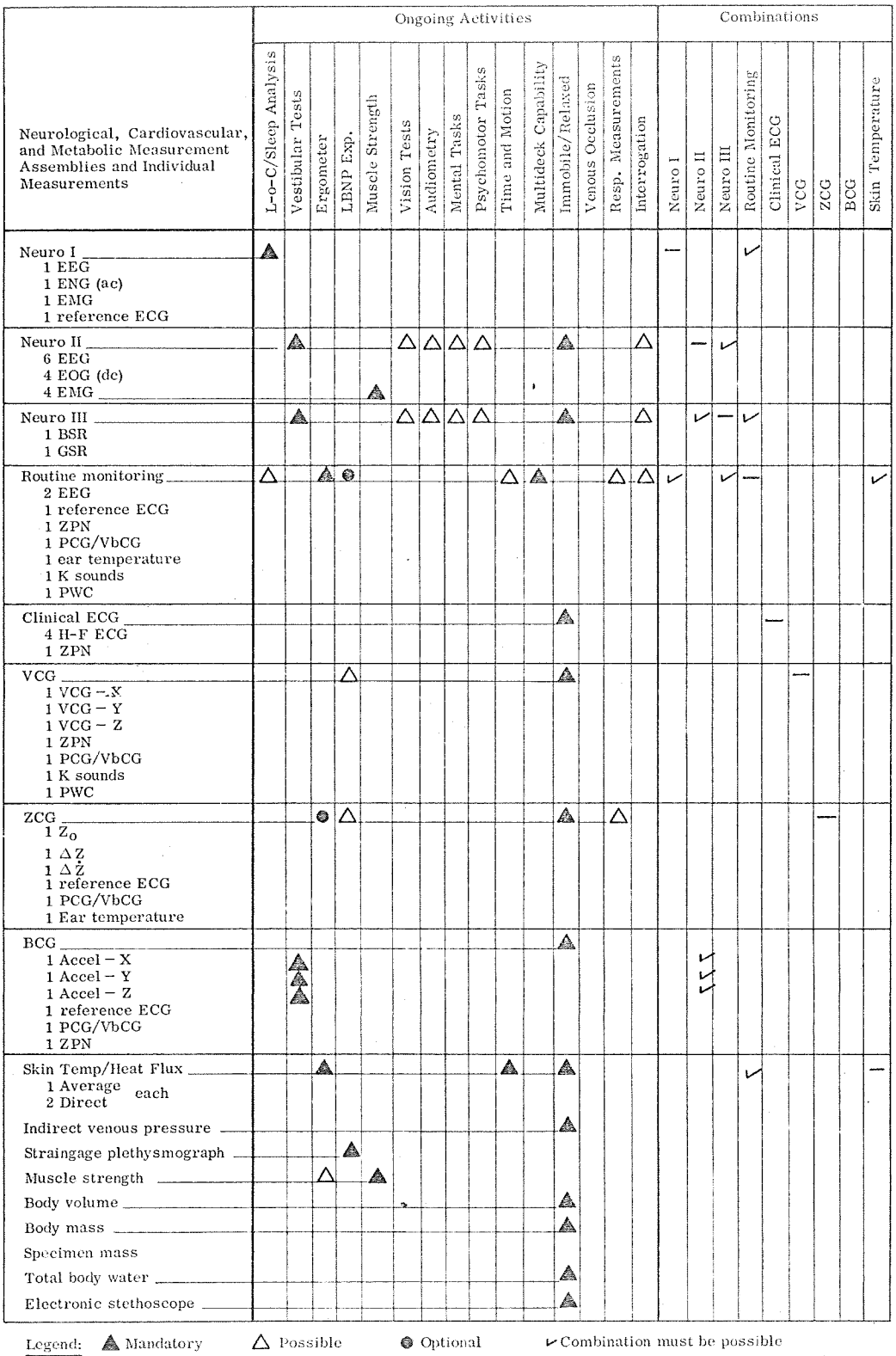


Fig. 2-1 Measurements Cross-Correlation Requirements

Additionally, signals requiring preprocessing in special-purpose electronic black boxes (before they are displayed or directed to the data management system computer) always have to appear at the same channel for the signal preprocessing electronics and the data management system to handle the incoming data.

Providing the IMBLMS data acquisition system with an infinite input signal selection flexibility would increase the complexity, size, mass, and power requirements of the body-worn electronics and the signal routing matrix in the IMBLMS console; and it would greatly magnify the computer programming complexity and costs. This increased complexity would also reduce the overall system reliability.

In addition, subject preparation time (selecting and exchanging of signal conditioners, electrodes, and transducers), as well as setup time for any particular experiment, would increase significantly, as would the probability of making errors in any one of these steps.

Trend detection in the various physiological parameters requires the repeated availability of identical channels on which to perform computer analyses. Consequently, the tasks of trying to develop predictive indices for the onset and severity of the deleterious effects of prolonged space flight and to establish the specific etiologies and mechanisms through which these effects are mediated would be seriously hampered if the onboard investigators were allowed to change channels indiscriminately.

In selecting the type and number of physiological data channels for each body-worn assembly, emphasis was placed on combining organ/system-related or time-related parameters. A typical example of the former is the Neuro II assembly, whereas the latter are represented by the VCG and ZCG assemblies.

Within the possibilities indicated on the right-hand side of Fig. 2-1 there is the capability for operating two assemblies simultaneously on the same subject. However, LMSC does not necessarily recommend that this be done on a regular basis, since the simultaneous use of two assemblies tends to reduce the subject's comfort and range of movement.

In summary then, LMSC believes that there is insufficient justification in providing additional data channel selection capability beyond that which is already included in its present preliminary B.4 design. However, within any given bio-belt assembly, the exact number and types of data channels can still be changed to accommodate specific NASA preferences before the flight hardware design is frozen. Even then, additional bio-belt assemblies of different configurations, together with their appropriate computer programs, could be manufactured for delivery by a Space Shuttle during a resupply mission at any time in the future.

The rationale for the selection of the primary and secondary or supporting parameters within each assembly are summarized in the following paragraphs.

2.1 NEUROLOGICAL MEASUREMENTS

2.1.1 Neuro I

This assembly is exclusively intended for level-of-consciousness assessment and sleep analysis. A single central parietal-occipital EEG lead is processed by a Frost analyzer, which displays the sleep level as discrete amplitude level shifts of its output signal. The ac-coupled horizontal EOG measures rapid eye movement (REM) activity during dream episodes, whereas the submandibular EMG registers head, arm, and gross body movement. The reference ECG is used to drive a cardiotachometer, the output signal of which is amplitude proportional to heart rate.

Although recording of the last three parameters is not essential for sleep analysis, per se, such would permit a more detailed assessment of the influence of weightlessness on percentage REM sleep, restlessness, and heart rate changes during normal and REM sleep.

Since use of the Frost analyzer constitutes a form of massive data compression, requiring only a minimal amount of very low speed magnetic tape recording to record a full 8-hour period of sleep data, it is essential that this advantage be preserved in recording the current ENG and EMG signals. LMSC, therefore, designed special integrators for these two parameters to allow the recording of activity per unit time at the same low tape speed.

2.1.2 Neuro II

The purpose of this measurement package is to record up to six leads of clinical EEG simultaneously. Ordinarily, the electrode positions are predetermined by their location on the MSC bathing-cap type holding device, but, by using other electrodes than those for which this holding device was designed, other lead configurations to meet special research objectives are possible.

Four channels of dc-coupled EOG permit recording of quantitative eye position (left or right, up or down) relative to the normal resting position, as well as direction, velocity, and acceleration of eye movement.

Four channels are available for EMG recording. These can be used as follows: one or two channels may be used to record the submandibular EMG in conjunction with the NASA neuro-cap to register head movement. In testing muscle function, it is essential to compare the performance of a muscle or muscle group against that of its contralateral, preferably simultaneously, during the execution of a common task. In addition, LMSC believes that in comparing the performance of two identical flexors, for instance, the functioning of the two corresponding antagonists should be measured simultaneously for a more complete evaluation. Without resort to intracellular recording in the event that one of the two flexors shows considerable recruitment during the task, the record from the extensors would show whether this recruitment results from atrophy of the flexor or from a tight extensor muscle unduly interfering with the flexor action.

These considerations have led LMSC to establish the requirement for the four clinical EMG channels, rather than the two recommended by NASA. Surface, needle, and insertable wire electrodes are provided to permit several methods of EMG recording.

It is anticipated that recording of the Neuro II channels will take place on a continuous basis during all vestibular function tests involving active rotation of the litter-chair and possibly during certain behavioral measurements. In the latter case, the EEG recordings could be analyzed for evoked brain potentials on the ground. Provisions will therefore be included to allow recording of the pertinent RLC, auditory testing, and visual testing data simultaneously with the Neuro II channels.

It should be mentioned that the three linear acceleration channels of the ballisto-cardiogram assembly can also be recorded during active rotation of the RLC. The triaxial accelerometer assembly can be attached close to the subject's head when he is seated on the RLC to record the acceleration levels to which his statokinatic labyrinth is exposed.

2.1.3 Neuro III

The body-worn signal conditioner Neuro III package provides the capability for recording the basal skin resistance and the galvanic skin response from different sites on the body. If these measurements were to be taken from the palmar and plantar surfaces, as has been suggested, task performances, such as tracking and time and motion, might be interfered with and, in turn, might interfere with the recording of the BSR and GSR from these sites. LMSC therefore recommends that finger electrodes be used instead of palmar electrodes and that conductive cloth socklet electrodes replace the plantar electrodes.

The instrumentation required generates a precise 10-microampere constant current signal, which is impressed across two subject electrodes. The resulting steady state and transient voltages across these electrodes are processed by two separate amplifiers. The BSR amplifier is dc-coupled throughout, whereas the GSR amplifier is ac-coupled, with a time constant of 8 seconds.

Although the vestibular measurements, vision testing, and audiometry belong in the group of neurological measurements, for convenience of organization of the material and assignment of program responsibility, they have been included in Section 6 of this volume (Sensory and Behavioral Measurements).

2.2 Cardiovascular Measurements

Certain secondary parameters in many of the cardiovascular measurement assemblies have been duplicated for several reasons. Although in most cases, recording of only the primary parameters would suffice to fulfill the measurement requirements stipulated in the Statement of Work, these requirements are measurement-oriented and

do not provide guidelines as to the detailed medical research function that the various elements of the flight IMBLMS should also be capable of providing.

For instance, in determining whether prolonged space flight causes an increase or decrease in R-wave amplitude, comparison of short segments of a recent ECG or VCG with similar segments taken early in the flight will be valid only if these two segments are recorded at the same point in the respiratory cycle (and if all skin-electrode interface resistances involved are closely matched). This clearly established the requirement for concurrently recording of respiration (ZPN).

The investigation of possible changes in the discrete events within each cardiac cycle, such as the isometric contraction time, the systolic ejection time, and the isometric relaxation time, can be accomplished only when the ECG or VCG are recorded simultaneously with the phono/vibrocardiogram (PCG/VbCG) and the (carotid) pulse wave contour (PWC).

Duplication of the supportive measurements in different assemblies is also dictated by LMSC's decision to design the various signal conditioners, calibration generators, A/D converters, and multiplexers within each assembly as hybrid or monolithic circuits wherever possible in order to minimize their size and enhance astronaut comfort. The size of each signal conditioner assembly will therefore be determined largely by the external packaging and the interface connectors required. The small size and mechanically delicate nature of micro circuits does not favor configuring them as plug-in units to be frequently interchanged. This would require a much sturdier construction, which would greatly increase their overall size.

Measurement assemblies that include a K-sound acquisition channel allow for the measurement of systolic and diastolic blood pressure. The K-sounds are transmitted to the IMBLMS console as raw signals, whereas the pressure levels and profiles are measured at the console. Together with a single-channel Reference ECG, these signals will be processed in LMSC's automatic indirect blood pressure monitor.

Specific characteristics of the individual measurement assemblies are discussed briefly in the following paragraphs.

2.2.1 Clinical ECG

This assembly permits simultaneous acquisition of the signals from the extremity electrodes and from a single precordial electrode. All four signals are received at the control module as wideband signals, allowing display of the signals and their composites as either high-frequency ECG or, after activation of the appropriate lo-pass filters standard bandwidth ECG. Generation of the augmented limb leads is accomplished by switching at the signal input panel (SIP).

For acquisition of V_1 through V_6, it is necessary to use a precordial electrode, which can be of either a miniature suction-cup type or a reuseable stick-on type (as yet to be developed). It is also possible, of course, to attach six regular electrodes to the chest and attach the lead sequentially to each of these electrodes. The use of a switching arrangement on the body-worn assembly for this latter method is not recommended, however, because this would significantly increase the overall size of the assembly.

The rationale for including the ZPN in this assembly was explained earlier.

2.2.2 VCG

The vectorcardiogram assembly is designed to allow VCG acquisiton according to the system developed by Frank. The Frank resistor network will be included in the body-worn assembly. A cardiac dipole locator will be included as an accessory to allow exact placement of the I, E, C, A, and M circumthoracic electrodes at the level of the heart's dipole. Accurate measurement of the shift of the heart along the body's Y-axis as the result of weightlessness is also an important research objective.

The rationale for including ZPN, PCG/VbCG, and PWC in this assembly was presented earlier. Inclusion of a K-sound amplifier will allow the periodic measurement of systolic and diastolic blood pressure while the VCG is being recorded during exercise.

2.2.3 ZCG

The primary purpose of recording the impedance cardiogram is to measure stroke volume, according to the Kubicek method. The PCG/VbCG is used here to determine systolic ejection time, whereas the reference ECG is needed to measure heart rate, which is used in turn to convert stroke volume into cardiac output.

Since there are reasons to believe that cardiac output depends to some extent upon body temperature, this assembly includes provisions for the simultaneous recording of ear canal (body) temperature.

2.2.4 BCG

Ballistocardiography is the technique of recording the internal forces generated inside the body in response to the movements of the heart and the pulsatile circulation of the arterial blood through the major arteries. As directed by NASA, only the linear acceleration in the three axes will be recorded; this will be done while the subject is strapped to a lightweight frame, free floating in the cabin.

Inclusion of a reference ECG and a PCG/VbCG channel permits the measurement of the exact time-relationships of electrical, mechanical and hemodynamic cardiac events and of the delay times between cardiac events and their reactions on the total body mass.

The ZPN establishes their interdependence on the phase of the respiratory cycle.

2.2.5 Routine Monitoring

The routine monitoring assembly is a general-purpose data acquisition package, which enables monitoring of vital signs under a wide variety of conditions. It can be used either by itself or in conjunction with certain other measurement assemblies to provide a more complete cross-correlation capability, specifically intended for research purposes.

In addition to heart rate, respiration rate, phonocardiogram, ear canal (body) temperature, arterial blood pressure, and pulse wave contour, this assembly includes two channels of EEG waveform recording. The latter will not ordinarily be used during routine monitoring, but employed only as required, for instance, during behavioral tests.

The measurement module on which the basic monitoring parameters are displayed contains special circuitry, which derives the pulsewave transit time by measuring the time interval between the R-wave of the reference ECG and the arrival of the subsequent arterial pulsewave at some distal point on the body (PWC). This feature is also included in the VCG assembly. LMSC's reasons for measuring pulsewave transit time, rather than to convert this parameter into pulsewave velocity, were explained in detail in the Phase B·3 documentation.

The inaccuracies that result from computing pulsewave velocity from pulsewave transit time would increase even more, if, for instance, k-sounds were used as the second parameter, as has been suggested. There is the obvious disadvantage of being able to measure pulsewave velocity only during the short time between the systolic and the diastolic endpoints of cuff deflation in the course of indirect blood pressure measurements. (The cuff deflations already cause variations in pulsewave velocity in their own right.) Also, the location of the K-sound microphone may vary by as much as 1 inch from one measurement to the next, as a result of either different initial placement of the cuff or subject motion. Notwithstanding certain minor disadvantages that may be associated with the use of another sensor for pulsewave contour acquisition, LMSC believes that the advantages of doing so far outweigh the disadvantages and has therefore incorporated a photoelectric phethysmograph pickup in its design of the pulsewave transit time measurement system.

2.2.6 Skin Temperature and Heat Flux

The skin temperature and heat flux measurement assembly contains three measurement channels for each of these parameters. One channel provides the average skin temperature from 12 weighted sensor locations; the other two temperature channels permit

direct measurement of the actual temperature from two randomly chosen locations anywhere on the body. Another channel provides the weighted heat flux from 12 heat flux transducers, and two additional channels measure local heat flux directly.

There is a total of 14 dual sensors, each of which includes a heat-flux transducer and a thermistor bead. This permits concurrent measurement of skin temperature and heat flux from the same sites of the body.

LMSC advises against changing the weighing factors of either the average temperature or heat flux transducers in flight because of the extremely complex and costly facilities that would have to be developed to allow accurate onboard recalibration for either measurement.

The rationale for the use of heat-flux measurements instead of or in addition to skin temperature, as well as a description of the basic characteristics of heat flux transducers, is included in Appendix C.

2.2.7 Voice Communication and Calibration

All of the major measurement assemblies include provisions for two-way voice communication between the operator and the subject. This voice link also allows for remote activation of the calibration circuitry included in each assembly. Additionally, the subject can manually activate an external calibration pushbutton when so requested by the operator when an assembly is being operated in the hardline backup mode.

2.3 OTHER CARDIOVASCULAR MEASUREMENTS

Some particulars of cardiovascular measurements and techniques other than those included in the bio-belt assemblies discussed previously are presented in the following paragraphs.

2.3.1 Limb Plethysmography

The use of plethysmography as it relates to the measurement of lower leg volume and blood flow during exposure to lower body negative pressure is discussed in Appendix B, page VI-5/34. The USAF Academy development of a capacitance plethysmograph for NASA is exclusively directed towards this one application.

LMSC recommends that the IMBLMS plethysmographic capability be made sufficiently flexible to perform segmental plethysmography on the legs, arms, toes, and fingers. Segmental plethysmography permits the recognition and/or localization of disease or damage to the vasomotor center and sympathetic pathways and assists significantly in determining the degree of central and peripheral arterial disease during flights of extended duration by means of a number of simple test procedures. These include measurement of crest time, rate of rise, one-half rise time, net area, reactive hyperemia, constant digit volume, volume increase rate, arterial obstruction, and aortic regurgitation.

Inclusion of segmental plethysmography would therefore greatly expand the IMBLMS diagnostic capability in the clinical area. Following an accident, for instance, the decision to keep the patient on board or to return him to earth may hinge significantly on the findings of a thorough plethysmographic evaluation.

The LMSC strain-gage plethysmograph included in the B·4 preliminary design includes nonmercury strain-gages, which can be made up in sizes from as small as 40 millimeters to 50 centimeters in length for instant application at any site on the extremities. It thus has the capability of performing the full range of segmental plethysmographic measurements specified above. Since these strain gages are only 1/8 inch in cross section, they occupy minimal storage and utilization space; and they can be applied to any site in about 15 seconds.

Further advantages of the LMSC plethysmograph include pushbutton calibration for either volume pulse or blood flow at any time during a measurement run, visual zero-centering of the bridge for maximum accuracy, and electronically controlled occlusion cuff pressure and duration for the measurement of blood flow via the pneumatic distribution unit.

The LMSC plethysmograph design is based on the original work of A. J. M. Brakkee (J. Appl. Physiol. 21(2), 701, 1964), subsequently modified and improved by G. L. Loos and Co.'s Fabrieken, Amsterdam, as a commerically available clinical instrument. This company has generously allowed LMSC to use the schematic diagrams of its instrument for further adaptation of the IMBLMS requirements.

2.3.2 Electronic Stethoscopy

Since hearing can conceivably deteriorate during long-term space flights, LMSC has included a portable electronic stethoscope as part of the IMBLMS clinical capability for use by the physician/astronaut. This unit allows recording of heart, lung, and abdominal sounds on tape for visual comparison of the waveforms with previously recorded or future information. Several commercial electronic stethoscopes were evaluated, but, since their frequency response characteristics were found to be inadequate, LMSC undertook the development of a completely new transducer and amplifier, which covers a frequency range from approximately 1 to 5000 Hz. Frequency emphasis and deemphasis in 5-db steps up to a maximum of +15 to -15 db at both low and high frequencies, as well as a sharp subaudio frequencies cutoff filter, are provided. Details of this stethoscope are contained in Appendix C.

2.3.3 Additional Measurement and Recording Techniques

Appendix C includes additional discussions of measurement and recording techniques pertinent to the preliminary IMBLMS design. In some cases, these discussions pertain to new or refined measurement techniques; in others they are concerned with actual laboratory verification of such methods and with establishing compatibility of equipment and recording techniques with the rest of the IMBLMS complex. Of specific interest in terms of the neurological, cardiovascular, respiratory, and metabolic measurements are the following topics:

(1) Electro-oculogram integrator
(2) Electromyogram integrator
(3) Automatic blood pressure monitor
(4) Exercise cardiotachometer

(5) Electronic stethoscope

(6) The measurement of heat transfer rates

(7) Respiratory measurement system

(8) Total body volume measurement system

(9) Biochemical laboratory verification

(10) Validation of indirect peripheral venous pressure technique

Specific details of all individual measurements are contained in Appendix B.

Section 3
RESPIRATORY MEASUREMENTS

The respiratory measurement requirements data sheets have been specifically structured to reveal and quantify any changes that may occur in the respiratory system as a result of weightlessness or other factors in the artificial environment. Data from these measurements will also provide information on any bronchopulmonary abnormality that may develop and make possible an early differential diagnosis and institution of therapeutic procedures.

Theoretical considerations suggest that prolonged exposure to weightlessness will not significantly affect the respiratory system. However, because of the weightless diaphragm and chest wall, it is expected that precise measurements will reveal a slight shift of the tidal volume into the normal inspiratory reserve volume (shallow breathing) and a consequent decrease in vital capacity. Since the chest wall is normally assisted by gravity in falling back into position, expiration will require more active muscular effort. Nevertheless, since the human respiratory system is not entirely gravity dependent, it is expected that the normal responsive adjustment of man will adjust to the effect of weightlessness on the respiratory system. However, prolonged exposure in an artificial atmosphere with possibe toxic trace contaminants may produce changes in the mechanics of breathing.

3.1 VALUE OF MEASUREMENTS AS PULMONARY SCREENING TESTS

Knowledge of the specific hazardous conditions to which astronauts may have been exposed would suggest the specific pulmonary tests most valuable for quantifying any changes that may occur and provide information to judge the effect on mission performance.

Prolonged exposure to irritating contaminents could produce bronchoconstriction, mucosal congestion, or edema. Data from the maximal inspiratory and expiratory flow rates and airway resistance measurements would establish the adequacy of the pulmonary function and provide information for making a judgment for permitting the exposed personnel to continue the mission.

Data accumulated from the respiratory measurements will contribute to the onboard clinical capability of IMBLMS, since they will serve as screening tests of pulmonary function. Any developing abnormal pulmonary function would be readily detected from the results of these measurements. They will also serve to monitor any respiratory therapeutic procedures instituted by the clinical care unit.

3.2 SELECTION OF METHODS AND TECHNIQUES OF MEASUREMENT

Medical pulmonary disease clinics and academic respiratory research laboratories have accumulated extensive experience with specific methods and techniques for each of the various respiratory measurements. The LMSC staff selected the methods and techniques for the 26 respiratory measurements after extensive sessions with medical consultants actively working in respiratory physiology and exercise pulmonary function testing. Except for the adaptation of the measurement techniques and their related equipment to operation in weightlessness and other constraints imposed by the spacecraft, the traditional methods of performing the tests have been followed.

The measurement requirements data sheets essentially treat one or more individual respiratory measurements requiring the same equipment and employing similar techniques of measurement. Particular attention has been given to an assessment of the accuracy of the various measurement techniques for securing significant measurable data.

Due consideration was given to methods and techniques requiring the shortest period of time and the minimal amount of expendibles and to the use of a significant number of elements of the metabolic analyzer developed by NASA for Experiment M-171.

The measurement grouping in a sequence of operations selected on the basis of similarity of technique of measurement, equipment commonality, and logical flow of information is presented in Table 3-1. The parameters measured in each operation, the calculations required, the inspired gas and the special equipment items required for the various measurements are tabulated.

Anatomical dead space, which consists of airways not lined with respiratory epithelium, may be measured post mortem from a cast of the bronchial tree or in vivo by gas dilution methods, as described by Fowler, i.e., inspiration of a single breath of 100 percent oxygen and analysis of the expired air by using a rapid, continuous N_2 gas analyzer. Physiological dead space is a volume of gas that is inspired and expired but takes no part in gas exchange in the alveoli, i.e., does not mix with alveolar gas.

The functional concept of dead space is intimately associated with that of alveolar gas and was therefore selected as the measurement that would supply the most useful data. The technique selected does not require a special gas, such as O_2, and is based on the volume of gas that is inspired and expired but takes no part in gas exchange in the alveoli. The measurement is made from $\dot{V}_{CO_2}$ and $P_{a_{CO_2}}$ by assuming that $P_{A_{CO_2}}$ equals $P_{a_{CO_2}}$. This is based on the premise that blood in each pulmonary capillary reaches complete equilibrium with the alveolar gas to which it is exposed. A mean alveolar P_{O_2} and P_{CO_2} can be established with reasonable accuracy. In addition, the parameters established in this technique of measurement are intimately related to those in subsequent measurements and permit an overall reduction in time to perform such related respiratory measurements.

A second tradeoff was conducted in the selection of the technique for measuring functional residual capacity. The traditional open-circuit method, based on the principle of washing all the nitrogen out of the lungs by inspiring N_2-free oxygen and measuring it, was first considered but was abandoned for the following reasons. The quantity of N_2-free oxygen necessary for inspiration by each crew member for a 2- to 7-minute measurement period once each week poses a considerable logistics problem. Also, the size of the spirometer (or collecting bag), previously flushed with oxygen, for collection of the expired gas, would unnecessarily complicate the equipment design. In addition, this technique would require a considerable amount of time.

Table 3-1

RESPIRATORY MEASUREMENT REQUIREMENTS

Measured Sequence	Title and Description	Measured Parameters	Calculations	Inspired Gas	Principal Equipment Required for Respiratory Measurement
1	Respiratory rate (RR)	Measured from start of inspiration from flow meter signal on a time base	$RR = \frac{180}{\text{Elapsed time - for 3 breaths}}$	Various mixtures	Flowmeter on time base
2	Lung volumes and flow rates	(VC), (FEV_1, FEV_3), (V_T), (IC), (ERV), ($\dot{V}_E$), (MEF), (MIF), & (MVV)	$V_{BTPS} = V_E\left(\frac{310}{273 + T_{mC}}\right)\left(\frac{P_B - P_m - H_2O}{P_B - 47}\right)$	Air	Flowmeter, mouthpiece, flow to volume integrator
3	Respiratory dead space (V_D)	$F_{A_{CO_2}}$, $F_{E_{CO_2}}$ V_E, $F_{I_{CO_2}}$	$V_D = \left(\frac{F_{A_{CO_2}} - F_{E_{CO_2}}}{F_{A_{CO_2}} - F_{I_{CO_2}}}\right)(V_E)$	Air	Mass spectrometer, mouthpiece, spirometer
4	Oxygen consumption ($\dot{V}_{O_2}$), carbon dioxide production ($\dot{V}_{CO_2}$), gas exchange ratio (R)	$\dot{V}_{O_2}$, $\dot{V}_{CO_2}$, R, V_E, $F_{E_{N_2}}$, $F_{I_{O_2}}$ $F_{I_{N_2}}$, $F_{E_{O_2}}$, $F_{E_{CO_2}}$, $F_{I_{CO_2}}$	$F_{I_{CO_2}} = P_{I_{CO_2}} / P_B$ (1) $\dot{V}_{O_2} = \dot{V}_E\left[\left(\frac{F_{E_{N_2}} \cdot F_{I_{O_2}}}{F_{I_{N_2}}}\right)\right] - F_{E_{O_2}}$ (2) $\dot{V}_{CO_2} = \dot{V}_E\left[F_{E_{CO_2}} - \left(\frac{F_{E_{N_2}} \cdot F_{I_{CO_2}}}{F_{I_{N_2}}}\right)\right]$ (3) $R = \dot{V}_{CO_2} / \dot{V}_{O_2}$	Air	Flowmeters, mouthpiece, mass spectrometer, spirometer
			(1) $\dot{V}_{O_2} = V_I F_{I_{O_2}} - \dot{V}_E F_{E_{O_2}}$ (2) $\dot{V}_{CO_2} = \dot{V}_E F_{E_{CO_2}}$	Oxygen	Oxygen supply, flowmeters, mouthpiece, mass spectrometer, spirometer
5	Alveolar oxygen and carbon dioxide partial pressure	$P_{A_{O_2}}$, $P_{A_{CO_2}}$	None required	Air	Mouthpiece, mass spectrometer
6	Minute alveolar venitlation ($V_{A\,min}$)		$\dot{V}_A = \Sigma\left[\frac{(V_E)(F_{E_{CO_2}})}{F_{A_{CO_2}}}\right]$ mℓ/min	Air	Mouthpiece, flowmeters, mass spectrometer, spirometer
7	Cardiac output(Q) by indirect method	$\dot{V}_{CO_2}$, $F_{\bar{V}CO2}$, $F_{A_{CO_2}}$	$Q = \frac{\dot{V}_{CO_2}}{C_{\bar{v}_{CO_2}} - C_{a_{CO_2}}}$	Select one gas mixture 6.5% CO_2 or 8% CO_2	Mouthpiece with special valves, mass spectrometer, gas mixture, rebreathing bag
8	Functional residual capacity (FRC)	V_{SPIR}, F_{He_1}, F_{He_2} (spirometer volume)	$FRC = \frac{V_{S_1}\left(F_{He_1}\right)}{F_{He_2}} - V_{S_2}$	He = 10% O_2 = 20% N_2 = 70%	Mass spectrometer, gas mixture, spirometer
9	Lung diffusing capacity (D_{CO})	$F_{I_{He}}$, $F_{A_{He}}$, $F_{I_{CO}}$, $F_{A_{CO}}$, V_A	$D_{CO} = \left(\frac{(V_A)(60)}{713t}\right) \times fn\left[\frac{\left(\frac{F_{A_{He}}}{F_{I_{He}}}\right) F_{I_{CO}}}{F_{A_{CO}}}\right]$	CO = .03% He = 10% O_2 = 20% N_2 = 69.7%	Mass spectrometer, gas mixture, spirometer
			$V_A = \left(\frac{F_{I_{He}}}{F_{A_{He}}}\right)(V_I)\,(0.78)$		
10	Flow-rate-volume ($\dot{V}$ - V) loop	Graphic presentation of all lung volumes and flow rates	Note: Display (V_T), (VC), (TLC), (FRC), (ERV), (IRV) and (IC). Volume - velocity loops will be correctly aligned in proper relationship to FRC on volume axis	Not applicable	Flowmeter, mouthpiece, flow to volume integrator and CRT
11	Maximum inspiratory and expiratory pressures ($P_{E\,max}$ and $P_{I\,max}$)	$P_{E\,max}$, $P_{I\,max}$	None required	Air	Sliding orifice and pressure transducer
12	Airway resistance (R_A)	Flow in L/sec mouthpiece, pressure	$R_A = \frac{\text{Momentary pressure rise}}{\text{Flow rate}}$	Air	Interrupter (chopper) and pressure transducer
13	Lung compliance (C_L)	Lung volume transpulmonary pressure	$C_L = \frac{V_1 - V_2}{P_1 - P_2}$ or $\frac{V_2 - V_3}{P_2 - P_3}$	Air	Esophageal balloon and pressure transducers

The closed-circuit technique with helium used as the test gas was selected. By switching to the test gas at the end of a normal expiration, the functional residual capacity is calculated. The 7-liter spirometer presently designed and accepted by NASA is more than adequate to hold the N_2 rebreathing mixture; the amount of gas required is less, thus reducing the logistics problem, and the time required for rebreathing the mixture is much shorter than the nitrogen wash-out technique.

Similar evaluation and tradeoff considerations have been applied to other measurements, such as lung diffusing capacity and airway resistance.

3.3 GROUPING OF MEASUREMENTS

In the absence of a firm experiment protocol for the respiratory measurements, a measurement sequence based on an orderly flow of experimental data has been selected. The 26 individual measurements have been listed in 13 experiment operations. The lung volumes and flowrates represent the largest group of measurements. Oxygen consumption, carbon dioxide production, and gas exchange ratios fall into a group because of similarity in method of performing the measurements and type of data produced.

Alveolar oxygen and carbon dioxide partial pressures represent the third group, again, based on similarity in method of measurement, equipment required and anticipated information needs of the onboard investigator.

The remaining measurements are represented in individual experiment operations to permit the greatest degree of flexibility in adjusting the measurement to system to the experiment protocol.

3.4 ADDITIONAL MEASUREMENTS RECOMMENDED BY LMSC

Additional measurements recommended by LMSC are maximum inspiratory pressure, maximum expiratory pressure, and the velocity/volume loop graphic display. These measurements are recommended because of the unique information they provide on the pulmonary function. The maximum inspiratory and expiratory pressure measurements

are essentially the Valsalva and Muller procedures and are recommended as a method for quantifying the strength of the respiratory muscles at periodic intervals during flight. The velocity/volume loop method is recommended as a graphic presentation of lung volumes and flow. When properly calibrated and aligned in correct relationship with a previously determined FRC, it provides a very rapid overall analysis of a subject's pulmonary performance.

3.5 MEASUREMENTS RECOMMENDED FOR DELETION

Lung compliance and lung diffusing capacity are recommended as prime candidates for deletion from the series of respiratory measurements. The added equipment required, the difficulty in obtaining meaningful measurements, and possibly anxiety and discomfort to the subjects are the reasons for this recommendation. The capability to measure these parameters could be added later, when specifically indicated by previous flight data.

3.6 SUMMARY

The IMBLMS respiratory measurement requirement data sheets include the more sophisticated pulmonary measurements that are usually performed only in cardiopulmonary laboratories of large medical centers. The assembly of measurement equipment to meet these requirements will make possible applications in situations other than in the spacecraft environment. An example is a compact, easily operated pulmonary screening assembly for use in a doctor's office, clinic, or small hospital. The capability for detection of altered patterns of pulmonary function in patients could be made available in the smaller medical facilities.

Section 4
BIOCHEMISTRY AND MICROBIOLOGY MEASUREMENTS

The biochemical station for the flight IMBLMS will provide a capability for estimating selected diagnostic, prognostic, and investigative parameters of the body fluids during extended missions. This capability includes measurements in hematology, clinical chemistry, and microbiology. The capability for investigative studies is necessary to provide a greater understanding of man's dynamic responses to prolonged exposure to the stress of space flight. The effect of stress on the body metabolism is often reflected in the various entities that compose the body fluids. The measurement of certain of these parameters will provide significant medical status indicators as to the health of the subject. From the measurement data, information will be available to determine metabolic trends and proper interpretation of such metabolic trends will permit predictions of possible degradation of performance and health.

4.1 GENERAL REQUIREMENTS

The measurements to be made at the IMBLMS biochemical station are listed in Table 1-1. These measurements, selected as a result of current and previous studies, were made on the basis of:

(1) The medical significance of the body function being monitored
(2) The value of the data attained
(3) The state of the art of measurement instrumentation to accomplish the measurement
(4) The commonality of instrument usage
(5) The simplicity of operator manipulations
(6) The minimization of requirements for space, weight, and power

In addition to these measurement selection restrictions, the performance of clinical laboratory measurements is further complicated by the peculiar space environment, which precludes the applicability of the usual laboratory operational procedures.

Although most of the IMBLMS biochemical measurements are routinely performed in clinical laboratories, the following requirements must be met to perform these measurements in the environment of the space vehicle:

(1) Containment and handling of specimens and reagents to permit reactions to occur and to avoid dissemination of materials into the space cabin atmosphere

(2) Use of methods that permit the employment of small quantities of specimen and reagents

(3) Use of methods that avoid the necessity of extreme detail or extensive analysis time

(4) Use of equipment and standard and reagent systems that are stable for extended time periods

(5) Use of electrical and mechanical equipment that is qualified for operation in a space vehicle

The constraints dictated by these requirements allow only certain measurements to be made in flight. For other measurements that are desired, it is necessary to preserve specimens of body fluids and feces for return to ground laboratories for additional analysis.

4.2 BIOCHEMICAL STATION MEASUREMENTS

The measurements at the biochemical station will be accomplished primarily with a colorimeter, blood gases and blood pH electrodes, specific ion electrodes, a radioisotope counter, a total body water analyzer, an electronic hematocrit, an electronic blood cell counter, a TV microscope system, and a refractometer. Support provisions required for the preparation and manipulation of the specimens include a pipetter/diluter, a centrifuge, an incubator, a colony counter, and a slide stainer. Provisions applicable to the zero-g environment are required for acquisition of the biological samples. The analytical operations will interface with the IMBLMS data management system so that the results of analyses can be displayed, recorded, and stored or transmitted to ground.

4.3 CLINICAL CHEMISTRY MEASUREMENTS

Clinical chemistries will be determined essentially by colorimetry, potentiometry, polarography, and routine test tape reactions for urinalysis. Analytical instrumentation will also be required for the determination of total body water.

4.3.1 Colorimetry

Blood or urine measurements made with a colorimeter include total calcium, phosphorous, glucose, serum glutamic oxalacetic transaminase, serum glutamic pyruvic transaminase, alkaline phosphatase, bilirubin, hemoglobin, and red blood cell fragility. The Phase B-3 FBB studies demonstrated the feasibility of performing colorimetry measurements in the space vehicle environment. The primary problem area experienced in that study was the containment and transfer of liquids and the elimination of air from the reaction system. The procedural operations were cumbersome and time consuming. A new approach, based on the use of flexible, transparent plastic reaction-cuvette containers, has eliminated these problems. The use of this type of reaction-cuvette container also allows the minimization of fluid handling and transfer. Colorimetric measurements depend on light absorbance at 340, 415, 450, 560, and 575 nanometers. The chemical reactions for the enzyme measurements, i.e., SGOT, SGPT, and alkaline phosphatase, require incubation at a constant elevated temperature in the range of 35 to 37^{o}C. Therefore, the instrumentation must provide a mechanism for constant thermal control to $\pm 0.25^{o}$C.

4.3.2 Electrode System

Previous studies have established that this measurement of blood gases, blood pH, and certain specific ions of body fluids should be accomplished by potentiometric or polarographic techniques. An electrode system is therefore necessary to perform the required measurements of the partial pressures of carbon dioxide (pCO_2) and oxygen (pO_2) in blood; the hydrogen ion concentration in the blood and urine; the ionic activity of sodium, potassium, and chloride in plasma and urine; and the calcium ion activity in plasma.

During Phase B.4, NASA established a measurement accuracy requirement of 0.05 pH units for urine pH. This dictates that the pH of urine specimens be determined by electrode measurement instead of the urine test tape technique previously recommended.

In the laboratory verification testing of the nuclear fast red method for measuring total calcium, it was found that the determination of total calcium in plasma was unsatisfactory because of the small range of total calcium present. It would appear more relevant to determine the activity of ionic calcium in plasma, since it is unlikely that total plasma calcium will ever exceed the normal small range. In another phase of the laboratory verification testing, it was established that ionic calcium in plasma can be satisfactorily measured with a specific calcium electrode. It is, therefore, recommended that the total calcium measurement in plasma be replaced by the measurement of ionic calcium.

Experience with the Phase B.3 FBB demonstrated the need for precise temperature control of the electrodes and the specimens. The electrode blocks must provide efficient thermal control and heat transfer characteristics that allow rapid temperature equilibration of the specimen and minimize the response time of the electrodes. This is especially important for the accurate measurement of the blood pO_2 and pCO_2. Thermal control to provide temperature stabilization of $37^{\circ} \pm 0.1^{\circ}C$ is desirable. The design of the fluid channels in the electrode blocks will minimize the collection of residues or air that interferes with proper measurement and will provide conditions that minimize electrode drying and decrease maintenance operations.

4.3.3 Total Body Water Analysis

The measurement of total body water is a specified requirement. Previous considerations to space applicable methods for making this measurement indicated that the determination of ethanol in one of the body fluids after ingestion of the alcohol is a possible means of accomplishing this measurement. LMSC has investigated this approach by conducting laboratory testing of various body fluids for ethanol after subjects had ingested specified quantities of the alcohol. Analyses for ethanol were made by gas chromatography, and the total body water for the subject was then calculated on the

basis of ethanol concentrations observed. The results indicate that the method is for space application. A report of the investigation is given in Appendix C.

An alternate measurement method may be the determination of deuterium oxide concentrations, such as parotid fluid, in body fluids after ingestion of the D_2O. Studies of this method are in progress at NASA/MSC. It has been indicated as a feasible method, but definitive results are not yet available. The analytical method being used in this study is infrared spectroscopy.

At this time, it is suggested that the ethanol-gas chromatography method be used. Small gas chromatographic instruments to accomplish ethanol analysis and gas chromatographs for space flight applications have been designed.

4.4 HEMATOLOGICAL MEASUREMENTS

The hematological measurements to be made at the biochemical station include the hematocrit measurement; red blood cell, white blood cell, and reticulocyte counts; white blood cell differential, red blood cell morphology, and platelet estimation; bleeding time, clotting time, and clot retraction; red blood cell mass and survival; and plasma volume. Instrumentation to accomplish most of these measurements includes an electronic blood cell counter, an electronic hematocrit, a radioisotope counter, and a microscope.

4.4.1 Electronic Blood Cell Counter

In IMBLMS studies prior to Phase B-4, the use of the standard laboratory hemacytometer was considered for the RBC and WBC counts. However, the use of the hemacytometer presents problems for zero-g application, since diluted suspensions of blood cells are needed and considerable difficulty would be experienced in focusing the microscope on cells in the suspending fluid. Thus, attempting to do hemacytometer blood cell counts in a zero-g environment would be difficult, time-consuming, and highly inaccurate. To alleviate these problems, an instrument based on the impedance principle has been designed for counting red and white blood cells. A current is allowed

to flow between electrodes on either side of a small orifice (typically 100 microns in diameter). When a diluted saline solution of blood flows through the orifice, each blood cell produces an increase in impedance as it moves through the aperture and each momentary impedance increase is recorded as a counted cell. Knowledge of the sample volume, sample dilution, and total counts permits the calculation of blood cells per milliliter of blood. Whole blood dilutions are used for red blood cell counts, and hemolyzed blood is used for white blood cell count. The instrument electronics, in addition to recording counts, should also be capable of particle size discrimination. The instrument provides for a continuous, constant flow rate of sample through the orifice during the measurement time so that erratic responses are minimized.

4.4.2 Electronic Hematocrit

The hematocrit measurement is the measure of the relative volume of red blood cells in whole blood. The standard laboratory method for determining hematocrit is gravity dependent; and, if this approach is followed for the measurement in the zero-g environment, a specifically designed centrifuge would be required. However, an electronic hematocrit is easily adaptable to use in space so it will be used in the biochemical station. This instrument measures the relative concentration of red blood cells by means of a resistance measurement. It operates on the principle that red blood cells act as electrical insulators, while serum is a temperature dependent conductor. The resistance of a calibrated volume of blood is a function of the relative volume concentration of the insulating blood cells. The chief advantages of this method are rapidity of operation since only a small volume of blood sample is needed, and simplicity of final readout.

4.4.3 Radioisotope Counter

Isotope methods will be used to accomplish the required measurements for red blood cell mass, red blood cell survival, and plasma volume. The red cell mass and survival will be estimated by measuring the radioactivity emitted by Cr^{51} labeled red blood cells that had been previously injected into the subject's blood. Periodically, after the injection of labeled cells, blood specimens will be acquired and the radioactivity of the samples determined by placing the specimen container (probably a

syringe) in the well of the radioisotope scintillation counter. From the count obtained, the red cell mass and survival can be calculated.

The plasma volume measurement will be made by determining the dilution of a known amount of radioiodinated (I^{125}) serum albumin (RISA) previously injected into the subject's blood. Since the RISA distributes in the plasma compartment, the measurement of the radioactivity in a known volume of plasma and the apparent dilution calculated from this value will allow the derivation of total plasma volume. Measurement of the radioactivity in the plasma sample will be made in a manner similar to that described above for red cell mass and survival.

4.5 MICROSCOPE MEASUREMENTS

The white blood cell differential count will be made by the microscopic examination of a stained blood smear. Slide staining will be made with the slide stainer device provided at the biochemical station. The staining material and procedure will be a modified Wright's stain. The estimate of platelet concentration and the observation of red blood cell morphology will also be made from this slide. The reticulocyte count will be made from the microscopic examination of a blood smear stained specifically for reticulocytes.

The examination of all slide preparations will be made with a combined TV-microscope assembly. The binocular microscope is capable of producing magnifications of 100x, 400x, and 1000x while maintaining high resolution of the image field. The 1000x magnification involves oil immersion. A precision mechanical stage with vernier scales allows movement of the slide in two directions for accurate scanning and area identification of abnormal cells.

Attachment of the microscope to the TV camera can be accomplished without the necessity of removing the binocular eye piece. The TV camera can record and subsequently transmit to ground control any microscopic images of diagnostic value. It can thus be used to assist the onboard physician in verifying his interpretations.

4.6 ESTIMATION OF COAGULATION FACTORS

Blood coagulation normality or abnormality can be estimated by measuring bleeding time, clotting time, and clot retraction. Essentially, manual methods will be used to make these determinations. To determine bleeding time, the subject's ear lobe will be punctured and the elapsed time between the appearance of the first drop of blood and the cessation of bleeding observed. Clotting time will be estimated by observing the time elapsed from the appearance of the first fibrin thread when a wire is repeatedly inserted and withdrawn from a blood specimen. Clot retraction will be estimated by observing the withdrawal of the clot from the walls of a capillary tube containing the blood specimen.

4.7 MINERAL BALANCE STUDIES

In addition to the accurate measurement of consumed and left-over food and liquids and the measurement of feces and urine, performance of mineral balance studies will have to rely primarily on post-flight analysis of returned samples. The capability for accurately measuring body mass and volume are equally important to these studies, as are the results of certain biochemical measurements, which can be accomplished onboard. LMSC believes that it is essential that the weight of food packages be clearly marked to facilitate positive reporting of food consumed and left over. Each astronaut should maintain his own intake/output log, since it is clearly impossible to assign this task to any one crew member.

4.8 MICROBIOLOGICAL MEASUREMENTS

To conduct in-flight microbiological analyses for bacteria and fungi, capability is necessary for acquisition of microbiological samples, culturing of sampled microorganisms, performing antibiotic sensitivity tests, staining microbial smears on prepared slides, observing microorganisms, and recording and transmitting results to ground. In addition, it is required to preserve and transport cultures to ground for additional studies.

A manual culturing approach will be used for the microbiological measurements. Samples for culture will be obtained from the throat, skin, environmental surfaces, and areas suspected as sources of infection. Material from the samples will be cultured in special divided culture trays containing appropriate selective and differential sterile agar media. The trays will be prepared on the ground and transported and maintained under refrigeration until needed. The bacterial and fungal organisms for which monitoring and identification provisions are made will be selected from those reported to be common to man. Facilities will be available for incubation of cultures at ambient temperatures (22^{o}C to 25^{o}C) and at 35^{o} to 37^{o}C with the capability of introducing a 3 to 5 percent CO_2 atmosphere when necessary.

Since colonial morphology of microorganisms on culture media assists in their identification, an optical magnifying device (colony counter) will be used to enhance the observation of detail. This device can also be used in performing colony counts when needed. Cellular morphology of isolated microorganisms will be determined microscopically from stained microbial smears. Staining of the smears will be accomplished through the use of the type of slide staining device used for the staining of blood cells.

Antibiotic sensitivity testing will be accomplished by inoculating agar media contained in culture trays with suspected infectious organisms. Selected antibiotic containing sensitivity disk or similar devices will then be placed on the inoculated surface. After incubation, zones of inhibition will be observed to determine the organisms sensitivity to various antibiotic agents.

The microbial cultures and the stained microscopic slides will be preserved and stored for return to ground. The cultures, in their respective culture trays, will be preserved by replacing the trays in the refrigerator. The microscopic slides will be maintained in dry storage in appropriate slide containers.

Even though culture plates and microscopic slides will be returned to ground, changes in their characteristic appearance may occur during storage. To provide a record of their realtime characteristics, a camera system will be used to take photographs of the culture plates and microphotographs of the microscopic slides, both in color.

During the performance of the microbiological analyses, it may be necessary to prevent either the dissemination of microorganisms into the space vehicle environment or the contamination of culture media with extraneous organisms, or both. For this purpose, a microbiological barrier or hood will be provided. This device must completely contain the microbiological specimens and required working materials while allowing the experimenter on the exterior to view the work area and perform necessary operations through the use of gloves.

Section 5
METABOLIC MEASUREMENTS

Metabolic measurements include the following parameters discussed elsewhere in this volume:

(1) Body (ear canal) temperature (par. 2.2)
(2) Average and direct skin temperature and heat flux (par. 2.2)
(3) O_2 consumption and CO_2 production (Section 3)
(4) Balance studies (minerals) (Section 4)
(5) Total body water (Section 4)

Additional metabolic measurements are discussed briefly in the following paragraphs.

5.1 BODY MASS

This measurement will be accomplished by means of the Thornton body mass measurement device (BMMD), as modified to interface electronically with the IMBLMS data management system directly, rather than by means of its standard readout assembly.

5.2 SPECIMEN MASS

The measurement of smaller masses, such as left-over food and feces, will be performed with the Thornton specimen mass measurement device (SMMD), modified essentially as described above for the BMMD.

No suitable method has yet been developed for the measurement of volume or mass of liquids. It has been suggested that liquids could be frozen and their mass determined in the frozen state by means of the SMMD. Apart from the time involved, LMSC cannot recommend the handling of subzero temperature specimens on a routine basis. Development of a technique to measure liquid volume of mass remains a high priority and probably very costly item. It is suggested that the possible application of the

the principle used in the LMSC technique for measuring total body volume be further explored.

5.3 MUSCLE STRENGTH

It has been shown that even in the presence of early muscle disease or atrophy many patients are still capable of exerting a momentary static effort that is not significantly different from their normal performance. Only when the effort is repeated several times or continued for more than just a few seconds do the results of the pathological condition become evident. For optimal assessment of muscle strength, the measurements should therefore be made under protracted dynamic conditions.

The muscle strength unit obtains strength profiles and provides maximum resistive strength values during performance against a motor-driven dynamometer. The configuration of the dynamometer is such that it permits measurements of flexor and extensor strength of either the arms or the legs. To eliminate the necessity of developing a strong and heavy subject restraint system, the dynamometer will be wall-mounted at a short distance above the Space Station floor, thus allowing the subject to perform the arm measurements in the supine position and the leg measurements in the prone position while lying on a pallet underneath the dynamometer. Although the prone position for the leg measurements may result in slightly lower values than the subject may be capable of generating when seated in a chair-type restraint device, the preflight, in-flight, and post-flight measurements will all be performed in this same position and are therefore directly comparable.

It is expected that the dynamometer will require a maximum capability of 150 ft-lb of torque and have an adjustable angular velocity range of from 10 to 25 degrees per second over 90 degrees of arc.

Although the Exer-Genie, included in the FBB for these measurements, has been eliminated, it can still be retained in its conventional configuration as an additional exercise device. However, exercises of the nature of the dead weight lift should be forbidden. Individuals untrained in weight lifting, can readily over exert themselves

and incur various back injuries, such as strained or torn muscles or ligaments. Even intervertebral disk hernias or vertebral compression fractures are known to have occurred from such efforts. The already measured muscular disuse atrophy and osteoporosis in U.S. astronauts and the Russian cosmonauts, resulting from even relatively short exposure to the hypodynamic environment of space flight, clearly indicate the use of extreme caution in subjecting the body to muscular and skeletal overloads. The MSU included in LMSC's preliminary design significantly reduces the possibility of over exertion.

The measurement of muscle size will be accomplished by measuring the circumference of the forearms, upper arms, thighs, and lower legs under maximal tension at designated anatomical locations by means of a tape measure, graduated in centimeters and millimeters.

5.4 TOTAL BODY VOLUME

The requirement for a technique to measure total body volume has led to a laboratory verification program to evaluate the possibility of using an infrasonic technique. A low-frequency signal generator drives a transducer (loudspeaker) attached to a closed rigid container at a certain subsonic frequency of fixed amplitude. The resulting pressure fluctuations inside the container are picked up by a second transducer, which translates them into an electrical signal. If objects of increasing volume are inserted in the container, the pressure amplitude sensed by the second transducer increases linearly with the volume of the objects placed inside the container.

Although more work is required to perfect the system, the calibration curves obtained on an X/Y plotter and a DVM gave very satisfactory results in consideration of the rather crude breadboard system used and the fact that no attempt had yet been made to neutralize ambient noise.

Section 6
SENSORY AND BEHAVIORAL MEASUREMENTS

The requirements and background for sensory and behavioral measurements are considered here in terms of establishing a general position in and defining an approach in each measurement area. Specific measurement requirements stemming from these considerations are detailed in Appendix B.

The level of discussion varies with the specific measurement area being considered. Some measures are straightforward and are basically identical to those identified and implemented in earlier contract phases. This is true, for example, of certain visual and complex performance measures as well as time and motion study. Where a measurement has been revised, a tradeoff discussion may be presented, as in the area of short-term memory. In the visual area, particularly, a number of specific groundrules evolved under NASA direction, and the implementation approach is constrained to these requirements. In the auditory and psychomotor measurement areas, totally new systems have evolved so fairly extensive discussions of rationale and approach are presented. In the vestibular area, the measurement approach is well defined on the basis of an existing experiment plan.

For the investigator interested in a particular measurement area, this section provides the general introduction and background, supported by Appendix B and the engineering tradeoffs and implementation approaches presented in Volume IV.

6.1 VISUAL MEASUREMENTS

The specific requirements for visual measurement evolved from contributions from many sources within NASA, the scientific community, and aerospace contractors.

The measurements and the rationale for their inclusion are discussed in the following paragraphs; and specific physical and functional characteristics and recommended implementation techniques are presented in Appendix B. The vision testing devices are described in Volume IV.

The required visual measurements are the following:

(1) Depth perception
(2) Visual field
(3) Critical fusion frequency
(4) Phorias
(5) Visual Acuity
(6) Dark adaptation
(7) Photostress
(8) Brightness threshold
(9) Color sensitivity

6.1.1 Depth Perception

This complex process involves the use of many cues, both monocular and binocular. The conventional depth perception test principle concerns binocular disparity, i.e., differences in retinal images created geometrically as a result of the physical position of the eyes with respect to an object in space.

This cue can be readily produced by stereo imagery or by actual physical differences in the location of real objects in space. The stereo image technique was selected by LMSC for incorporation in the B.3 breadboard, but real object displacement has been indicated as the preferred measurement approach by NASA since it is the conventional technique used with astronauts. This measurement is accomplished through use of the Howard-Dolman apparatus, in which two vertical rods are presented to the subject at a 20-foot viewing distance. He is required to adjust the initially offset moveable rod until it corresponds in range to the fixed rod. While this technique emphasizes the retinal disparity cue, size cues play a small part in the judgments.

6.1.2 Visual Field

The object of this test is to prepare a retinographic map of visual sensitivity as a function of stimulus position and color. The purpose of this mapping is to determine the boundaries of the field and to discover any defects, such as scotomas and hemeanopsias. A target is moved along a meridian from perimeter to center of the field and the subject reports the appearance or disappearance of the object. This is done for 12 principal meridians, each passing through the line of fixation at 15-degree increments. Tests are performed separately for each eye. Figure 6-1 shows a representative normal map.

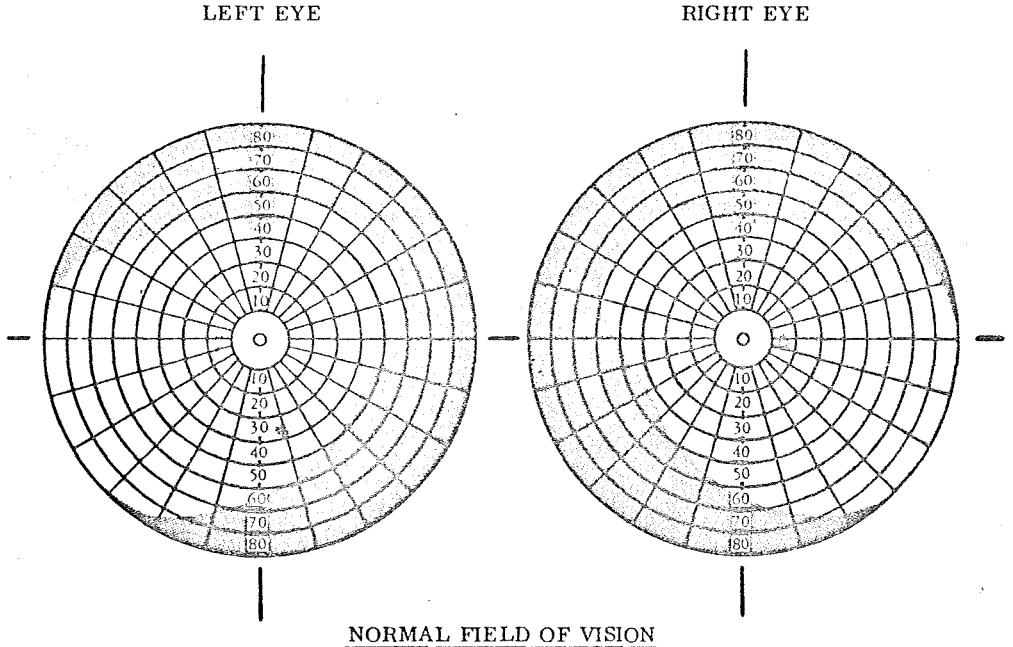


Fig. 6-1 Polar Plot of Normal Field of Vision

This measurement was included at the specific request of NASA. It was not included in the LMSC B.3 vision tester. It is expected that the test will be sensitive to changes in retinal sensitivity related to cardiovascular function. However, the technique is time consuming, not highly precise, and awkward to mechanize. It is therefore recommended that studies be conducted to ascertain whether other simpler measures, such as color perception or dark adaptation, will be sufficiently indicative of changes mediated by the same physiological mechanisms.

6.1.3 Critical Fusion Frequency

Successive flashes of light are perceived as flicker if they are below a certain frequency or as steady light if they are above this frequency. This critical flicker frequency, or critical fusion frequency (CFF), varies with level of adaptation, brightness, pupil size, field size, area and location of the retina stimulated, phase relationships, and stimulus wavelength. CFF has been used extensively to evaluate the effects of fatigue, aging, and drugs. In a sense, it is a window into the complex operations of the stresses imposed on the central nervous system.

6.1.4 Phorias

Phorias are deviations of the eyes from a coincident line of regard as a result of muscular imbalance. They are normally evidenced horizontally, vertically, or both when the stimulus to fusion is low. A test for phorias consists of presenting a separate stimulus to each eye under low illumination and measuring the discrepancy in the line of regard. NASA strongly recommends the use of the Risley prism-Maddox rod technique for these measurements. The Maddox rod is a cylindrical lens, which produces a line of light viewed by one eye. The Risley prisms are two opposed optical wedges, whose relative displacement can be adjusted to produce a deviation in the line of regard. The subject reports when a spot of light viewed by one eye through the prism appears to be coincident with the line of light viewed by the other eye through the cylindrical lens.

6.1.5 Visual Acuity

Visual acuity is a measure of the resolving power of the visual system defined as the reciprocal of the just-resolvable detail expressed in terms of visual angle units.

The following acuity measurements are used:

(1) Minimum perceptible – the finest single line that can be resolved

(2) Minimum separable – the smallest gap between two stimulus elements that can be resolved, measured with Landolt Cs or grating targets.

(3) Vernier acuity – the minimum resolvable offset or break in a line element of which one portion is displaced laterally with respect to the other

(4) Snellen – ability to recognize letters whose stroke, width, and size are scaled in terms of visual angle

NASA specifically requires a vernier acuity measurement and recommends that this be accomplished by means of continuously variable displacement of one line segment with respect to a reference.

6.1.6 Dark Adaptation, Photostress, and Brightness Threshold

Dark adaptation is a measure of the increasing sensitivity of the visual system when the eye is exposed to a low luminance or totally dark environment. The rate of adjustment and the final level of sensitivity is basically determined by the initial intensity level and the final intensity level to which the eye is exposed. Other differences occur as a function of the wavelength, the size, and the retinal location of the stimulus light.

Dark adaptation is expected to provide a key index to the sensitivity of the visual system, particularly as it might be influenced by retinal blood supply and attendant photochemical processes associated with cardiovascular effects of weightlessness.

Photostress is an index of the ability of the sensitized visual system to recover from an overload, such as a flash of light. It therefore provides a means of further assessing the effects of system sensitivity. It would be measured following a period of dark adaptation by holding sensitivity constant through use of a fixed brightness test field while presenting a flash of light, after which the recovery processes would be measured.

Brightness threshold will be an index of the terminal level of sensitivity as a function of time.

6.1.7 Color Sensitivity

While color sensitivity is a basic visual function, the precise mechanisms are not fully understood. It is known, however, that color sensitivity changes with physiological

stresses, such as hypoxia. The Russians report changes in the apparent brightness of colored test patches on the basis of experiments performed on at least two of their manned flights. The NASA guidelines specify anamaloscopy as the preferred measurement technique, and baseline data for the astronaut population are available. While this is not the technique used by the Russians, nor by LMSC in the B.3 vision tester, it is probably sufficiently sensitive to changes in apparent brightness, since it basically involves a manipulation of the intensity of stimulus sources at selected wavelengths.

6.2 AUDITORY AND CUTANEOUS MEASUREMENTS

The measurement requirements in the area of audition include pitch discrimination, temporal acuity, and speech intelligibility as new measurements. Also, LMSC recommends inclusion of the short increment sensitivity index (SISI) measurement.

Cutaneous measurements include absolute touch threshold, two-point touch discrimination, and vibrotactile thresholds.

Analysis of the measurement requirements indicates the desirability of employing similar procedures for all tests. Considerations must also be given to the spacecraft noise environment in terms of the practicality of making low-frequency (<500 Hz) measurements.

Throughout this effort, the participation of Grason-Stadler, Inc., specialists in psychoacoustic instrumentation, was of immense value.

6.2.1 Testing Techniques

A review of the auditory test requirements for the IMBLMS Program indicates that all have one general characteristic in common: they all require the systematic presentation of a stimulus and the monitoring of the subject's response to that stimulus until some indication of threshold, or discrimination ability, is obtained.

A single reliable experiment procedure common to all four tests could make the subject's task easier and less confusing, provide more uniform results, and decrease the amount and complexity of control equipment required.

LMSC recommends the so-called adaptive, rather than the classical methods. Instead of testing levels thought to bracket the subject's threshold, adaptive methods depend on the subject's performance to determine successive levels of stimulus presentation. In general, they involve the presentation of the test stimulus at a level easily detected and discriminated by the subject and successive trials entail increasingly fine discrimination until a threshold (by a previously agreed-to definition) is reached. The major advantage is that these methods are faster than the classical ones and tend to be as accurate if not more so. Well known investigators have developed variations of the adaptive method, as reported in Refs. 12, 15, 21 and 61.

6.2.2 Test Environment

Before any auditory testing, precautions will have to be taken to ensure that the subject is sufficiently isolated from the ambient noise environment. This means that, for each auditory frequency tested, the energy level of the ambient noise affecting the subject's threshold, i.e., the energy present in the critical band of the noise, must be less than his threshold at that frequency. If the noise level in the critical band exceeds this, the subject's threshold will be erroneously measured so the test will be invalid.

Steps can be taken to reduce the ambient noise level during testing. One is to design ventilation and other environmental control equipment and the machinery in the complex itself for quiet operation or to turn off such equipment and machinery temporarily. Another is to design the headsets used during auditory testing for maximum attenuation of the ambient noise. LMSC recommends use of an earphone and a circumaural muff – both perhaps incorporated into a helmet-type support unit. Data from Refs. 1, 2, 54, and 55 are pertinent to this point. An indication of the degree of attenuation afforded by such muffs is given in Table 6-1. Values given in the record column are derived from the work of Villchur and Shaw, along with ANSI 9-A coupler standards. It would be desirable to have a margin of 5 to 10 db below the figures given in the third and fourth columns.

Table 6-1
ATTENUATION AFFORDED BY MUFFS

Frequency	Approximate Threshold SPL, Entrance Ear Canal (db)	Maximum Permissible Ambient 1/3 Octave Noise w/MX41/AR (db)	Maximum Permissible Ambient 1/3 Octave Noise w/Special Muff (db)
125	27	20	40
250	20	17	30
500	10	15	30
1000	7	20	40
2000	9	30	50
4000	10	40	50
6000	15	40	50
8000	13	30	40

If these attenuation requirements cannot be met and the specimen level of the ambient noise is still above subject's threshold, it will be necessary to know the level of this noise and avoid trying to make absolute threshold determinations at these (probably the lower) frequencies. In tests other than the absolute threshold test, auditory signals will have to be presented at a fixed intensity well above this ambient level rather than above the subject's threshold (Refs. 1, 54, and 55).

6.2.3 Auditory Tests

The test for absolute threshold is administered first to obtain values that will be used in subsequent tests to define sensation level for each subject.

The pure-tone absolute threshold test is designed to determine the minimum detectable intensity, for each of the test frequencies (125, 250, 500, 1000, 2000, 4000, 6000, 8000, and 12,000 Hz). At each frequency, two 500-msec cue lamps (A and B), separated by a 500-msec interval, are operated.

On any given trial, a pure tone will be paired with only one of the cue lamps (50 percent probability, randomly selected), with a silent interval accompanying the other.

During a 2-second response period following the operation of cue lamp B, the subject's task is to press the button on the response panel associated with the cued interval during which the tone was presented. The intensity of the tone can vary from -10 db HTL to +54 db HTL across all frequencies. At any given frequency, its initial level will be +20 db HTL (Ref. 10).

The pitch discrimination test is designed to determine for test frequencies 1000, 2000, and 4000 Hz the minimum frequency difference detectable by a subject. At each test frequency, two 500-msec cue lamps (A and B), separated by a 500-msec interval, are operated. On any given trial, one cue lamp will be paired with the test tone and the other with a second comparison tone, differing from the other only in terms of its frequency. The occurrence of these tones in either interval is randomly determined, each having a 50 percent probability of being first. During a 2-second response period following the second tone, the subject's task is to press the button associated with the cued interval in which the tone appeared to be higher. The frequency of the comparison tone will vary 0.05 to 0.8 percent of the test frequency across all three test frequencies. Intensity of both tones will be held constant at +20 db HTL (Refs. 31 and 56).

6.2.3.1 Temporal Acuity

A method for testing the subject's ability to detect auditory flutter as a result of varying the length of interpulse intervals is outlined in the measurement data sheet (Appendix B). Since its introduction by Miller (Ref. 42), the test has been shown to produce a wide variety of often incompatible results. Even when results do agree, they are difficult to interpret in relation to any particular auditory (physiological) mechanism. The test further appears to be more susceptible than most to influence from nonexperiment factors, such as subject motivation and criteria for judgment (Refs. 15, 69, 70, 71, 72, and 73).

These discrepancies are probably a result of the number and complexity of parameters varied in the auditory flutter test. From the information contained in the measurement data sheets, it appears that the proposed test may also vary in terms of too many (at least three) major parameters: repetition rate, signal duration, and signal intensity.

If these parameters were carefully and systematically varied, the experiment would be too lengthy and of dubious value. Nevertheless, this test will be utilized, since the capability is inherent in the equipment.

As implemented, this test is designed to determine in a 1-second series of equal-duration noise pulses (10, 50, or 100 seconds) the minimum interpulse interval detectable by a subject. For each burst of noise at a given pulse duration, two 1-second cue lamps (A and B), separated by a 500-msec interval, are operated. On any given trial, one cue lamp will be paired with a 1-second series of noise pulses. The order of presentation of these signals is randomly determined, each having 50 percent probability of occurring first. During a 2-second response period which follows the second stimulus, the subject's task is to press the button associated with the cued interval in which the noise appeared to be pulsed. The interpulse interval will be varied from 2 to 32 msec. Intensity of both stimuli is constant at +20 db HTL.

6.2.3.2 Short Increment Sensitivity Index (SISI)

LMSC recommends that this test be included in the IMBLMS Program (Ref. 33). At least two characteristics of SISI justify its inclusion. First, it is easy to implement and requires very little time to present. Second, it is a good test for discriminating between conductive and sensorineural disorders, a potentially valuable tool if there is, in fact, damage to the auditory system as a result of space travel.

As recommended, this test is designed to determine for each of two frequencies (500 and 4000 Hz) the amount of intensity increment that can be detected by a subject. Two 1-second cue lamps (A and B), each paired with an identical fixed-intensity, fixed-frequency pure tone, and separated by a 500-msec interval, are operated for each frequency. On any given trial, a 200-msec 1-db or a 3-db intensity increment will be added to the second pure tone. The occurrence of the increment vs. the nonincrement interval is random, each having a 50 percent probability of being presented first. In any one trial, however, the probability that a 1-db increment will occur is 75 percent; that a 3-db increment will occur, 25 percent. During the 2-second response period the subject's task is to press the button associated with the interval during which he judges the intensity increment to have occurred.

6.2.3.3 Speech Intelligibility

This is a measure of the subject's ability to recognize spoken material presented against a noise background. Functional guidelines presented in the measurement data sheets indicate that well validated material be used, that it be presented in stereo, and that the subject's response be a repetition of the test material onto a separate tape, in turn stored for later analysis.

LMSC recommends that, in order to increase the speed of administering this test and to lessen the task of analyzing the subject's oral responses, a speech-intelligibility task similar to that used by Speaks and Jerger (Ref. 59) be used. This would consist of presenting some form of validated verbal material to the subject, who would respond by selecting the one of n alternatives that corresponds to the stimulus. A visual cue preceding the spoken material to alert the subject to the approaching task is recommended. Initial trials would be presented at a level of intensity well above the subject's threshold. Successive presentations would be made at reduced levels, through an adaptive technique consistent with the other measures. The estimated value of the intensitys threshold for speech would be stored for future transmission to the control base.

Test words (such as those in the Harvard phonetically balanced lists) would be taped and single words presented. During a response period following the word presentation, the subject's task is to scan a numbered word list (either printed or presented as a video readout) and insert a response associated with the visual word he judges that he heard. From trial to trial, the intensity at which the spoken material will be presented will vary from -10 to +54 db HTL.

6.2.4 Tactile and Vibratory Measurements

The initial B.4 measurement requirements called for cutaneous measures, namely, absolute tactile threshold and 2-point threshold. The rationale for these measures was discussed with NASA, and a decision was made to automate the tactile measure and perform the 2-point threshold measurement in a simple mechanical manner.

These tests can be carried out very efficiently with the equipment used in the absolute threshold test for hearing used to drive a separate transducer. Vibrotactile thresholds (Refs. 66 and 67) could be tested through the use of a simple bone vibrator, on which a small fiber is mounted.

The test is designed to determine for each of the two pulse durations (1 and 10 msec) the minimum intensity at which a pulse can be felt. Two 500-msec cue lamps (A and B), separated by a 500-msec interval, are operated for each of the two pulse durations. On any given trial, one cue lamp will be paired with a tactile pulse and the other with no tactile stimulus of any kind. The order of occurrence of the pulse and the no-pulse interval is random, each having a 50 percent probability of being presented first. During a 2-second response period following cue lamp B, the subject's task is to press the button associated with the interval during which he judges the vibrotactile stimulus to have been presented. The intensity of the stimulus will be varied from over a 64-db range.

The tactile threshold measurement would be carried out much as the absolute auditory threshold. However, a separate transducer capable of responding clearly to a dc pulse would be required. This device, placed above specific locations on the skin surface, would serve to produce discrete pulses of controlled amplitude as tactile stimuli. All signal generation and program control would be incorporated in the audiometer circuitry.

Other measures could be carried out with this equipment used in conjunction with the basic control flexibility and transducers now planned (Refs. 8 and 34).

Vibratory measures that parallel auditory measures of absolute threshold differential frequency discrimination, temporal acuity, and SISI could easily be accommodated within the capability of the basic audiometer logic. However, additional lower frequencies may be required; so power amplification would be necessary to drive the stimulators.

6.3 VESTIBULAR FUNCTION MEASUREMENTS

The vestibular function measurements consists of the following tests:

(1) Agravic perception (spatial orientation)
(2) Ocular counterrolling
(3) Semicircular canal threshold (oculogyral illusion)
(4) Angular acceleration threshold (whole body)
(5) Visual task within head rotation
(6) Coriolis (motion) sickness susceptibility

Except for the ocular counterrolling, test, the measurement techniques and hardware for the AAP M131 Human Vestibular Function Experiment (with modifications) are used for these tests.

The agravic perception and the ocular counterrolling tests measure the otolith function. The semicircular canal threshold and the angular acceleration threshold tests measure the semicircular canal's function. Since the oculogyral illusion is a more sensitive measurement of the semicircular canal's function than the whole body report, the angular acceleration threshold measurement will be used primarily as a backup technique for the semicircular canal threshold measurement in case of malfunction of the otolith test goggles. The visual task with head rotation and the coriolis sickness susceptibility tests measure the effect of stress in the form of angular velocity.

In general, all measurements involve use of the rotating litter chair, which is controlled precisely to provide constant angular accelerations and velocities about the subject's yaw axis and tilt positions in the subject's pitch and roll planes. The otolith test goggles and the rod and sphere with readout will be used with the agravic perception measurement, while only the goggles will be used with the semicircular canal threshold measurement. A CRT display and a hand controller assembly will be used for the visual task with head rotation measurement.

The photographic technique for measuring ocular counterrolling,as used by E. F. Miller and R. S. Kellogg, is recommended. Although dc couplers and infrared oculometers are capable of measuring relatively accurately the position of the eyes, no baseline data exists for ocular counterrolling measurements.

6.4 PSYCHOMOTOR MEASUREMENTS

The psychomotor measurement requirements were extensively reviewed for Phase B.4. The analytical and empirical work is described in detail in Appendix A, which includes a reference listing. The measurement requirements treated in this section are continuous control tracking, complex motor abilities, and fine motor abilities/steadiness.

As is characteristic with more complex psychological processes, almost any generally stated requirement is open to a wide range of interpretations, many of which could be construed as meeting the requirement. However, LMSC has attempted to develop a cohesive set of measurements, which depend on a consistent and well understood description of behavior. To this end, the services of Systems Technology, Inc., were invaluable. The approach taken is based on the application of manual control theory to the description and prediction of the human operator behavior in manual control tasks. This affords a baseline model or theory from which to structure tasks and an extensive body of empirical evidence to support specific developments.

6.4.1 Continuous Control Tracking

To satisfy this measurement requirement, LMSC has proposed the so-called critical tracking task, which measures the "effective time constant" of the operator performing first- or second-order two-axis compensatory tracking. In addition, a measure of tolerable instability for continuous two-axis homogenous order tracking is recommended. The control dynamics associated with these tasks provide the range of difficulty desired by NASA and are of the type that relate to functions associated with spacecraft control.

6.4.2 Complex Motor Abilities

This requirement calls for performance of two or more tasks simultaneously, with the subtasks capable of being conducted separately. This is accomplished by combinations of control dynamics and control stick characteristics in each of the two control axes. In addition, the manual control task may be performed when the subject is concurrently performing one of the complex performance tasks. A significant capability is to use

adapative techniques to continuously adjust the loading imposed on the operator by the primary task as a function of the level of performance he achieves in a secondary steady-state task.

6.4.3 Fine Motor Abilities

An extensive literature review was conducted to determine measurement requirements for this task and was supported by a brief empirical study, discussed in Appendix A. The intent was to measure the frequency-response characteristics of the forearm/hand/finger system as it applies a constant force to the hand controller for a specified time interval. This system will utilize the major control, display, and computational elements of the psychomotor tester to measure the amplitude and acceleration characteristics of the neuromuscular system in the range of 8 to 13 Hz in a single axis.

6.4.4 Additional Measurement Capabilities

The basic psychomotor measurement system is designed as a flexible tool. By making use of the control and display elements and recombining computational elements, a number of additional measurement capabilities can be accommodated. For this program phase, the device will provide the dynamics and instrumentation for the rotating litter chair tracking task. It is also planned to provide inputs and outputs necessary to drive a realistic spacecraft-type flight director/attitude indicator as a means of providing skill maintenance.

Additional measurement procedures that could be accommodated within the current concept are as follows with the recommended apparatus used without modifications:

(1) Control proficiency training and monitoring (tracking tests, random step tracking)

(2) Simulated attitude-damper failure management (first and second order subcritical task)

(3) Recreational complex-task learning and competition (e.g., multitask workload variations)

(4) Simulated tilt-table: ball-in-maze coordination test ($Y_{cA,B} = K_3/S^2$; LH = horiz, RH = vert) + maze CRT overlay)

(5) Velocity matching, time-to-go estimation, path prediction, etc. ($Y_c = K_1$, ramp and/or interrupted display)

(6) Visual motor reorientation (with axes of control rotated ± 90 deg with respect to axes of error display)

(7) Open-loop (eyes closed) force reproduction (like Soyuz 9)

(8) Various combinations of complex visual monitoring, audio, and discrete tasks (with other displays on panel used)

Measurement procedures with minor modification or accessory additions to the apparatus include:

(1) Simulation of realistic rendezvous, docking, and reentry tasks, with dampers on or off ($Y_{cA,B} = K_{1/S}$ or K_{2/S^2}, with actual spacecraft ADI and attitude control stick added and step and disturbance inputs included)

(2) Egocentric vertical localization (like Soyuz 9), (with black hood added, line on CRT, rotated, and cursors deleted)

(3) Human dynamic response: describing functions and remnant noise (like Soyuz 9) (with input generator and on-line describing function analyzer added)

(4) Simulation of LRC complex coordination tester (with foot pedals added, alphanumeric CRT used to present command and response lights, and supervisory computer added to store program)

(5) Simulation of any classical psychomotor test, e.g., pursuit rotor, steadiness rod-in-hole (with rotor path stored in supervisory computer, display path stored in CRT, and tracing performed with Z-axis stick)

(6) Free-finger tremor measurement (with signal from Z gram accelerometer on finger used in lieu of stick force signal)

The major elements and functions of the system are shown in Fig. 6-2.

The system chosen provides great flexibility in meeting the general requirements to conserve space and weight. Computations and procedures are automated to the extent that summary scores are available after each trial, even in a backup mode. When used in a fully automated mode, the computer will control the presentation of a series of trials, select dynamics, and perform summary computations on the performance scores.

The system provides for a range of relevant and well validated tests, based on the latest development in man/machine system theory. The configuration and parameters selected are basic to a wide range of spacecraft manual control and fine motor tasks.

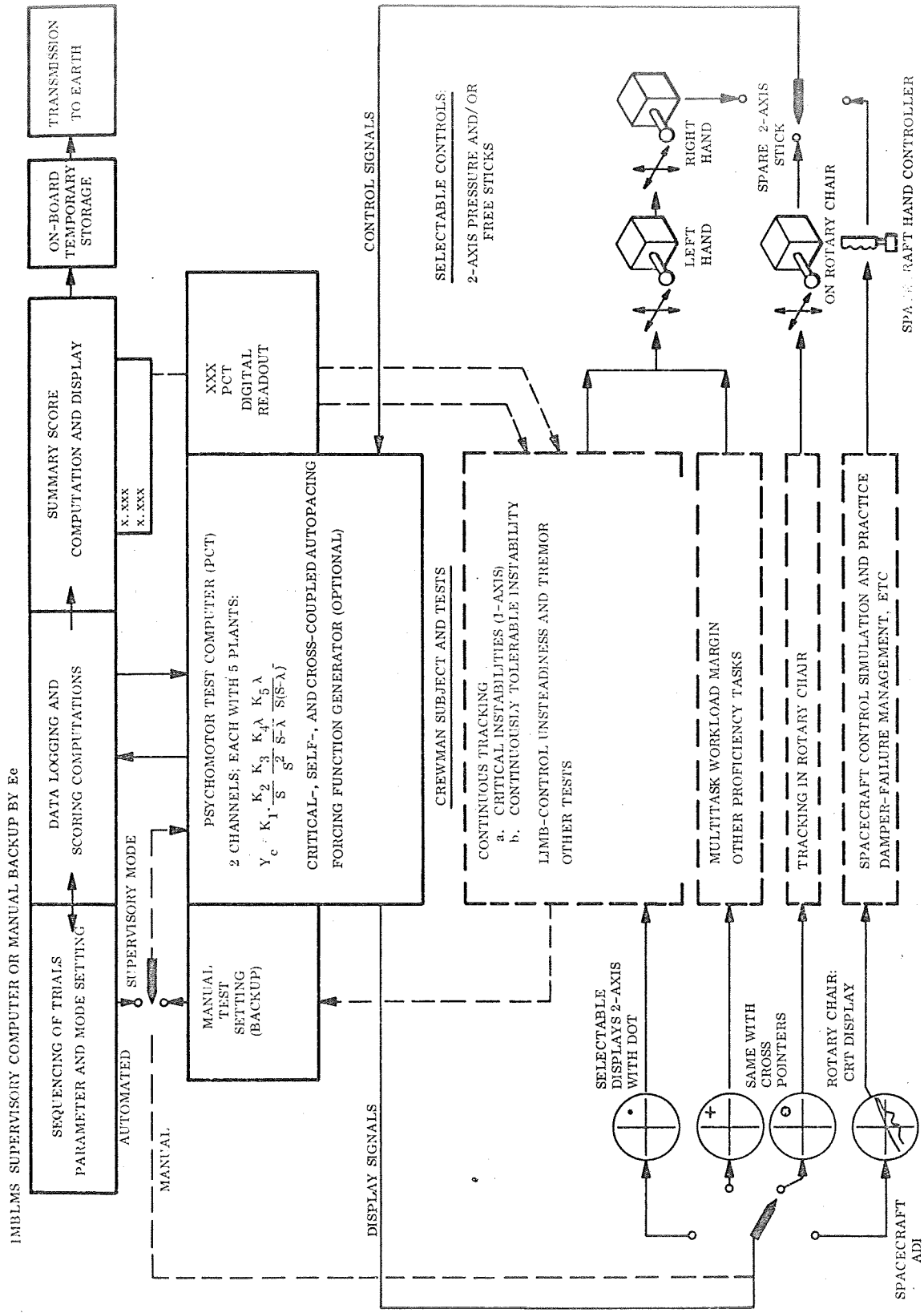


Fig. 6-2 Integrated Psychomotor Test Concept

The basic concept is to force the subject to his performance limit, revealing intrinsic capabilities, rather than calling for some arbitrary involvement, which has confounded the results of more classical approaches with a host of motivational variables. Most of the tests result from NASA and Air Force supported long-range development programs, in which test parameters, protocols, and results have been thoroughly validated. The basic technique was recently used in the NASA 90-day test.

6.5 TIME-AND-MOTION STUDY

This requirement is considered to be a general-purpose measurement technique applicable to assessing relative gross motor activities. It will be met through the provisions for a television camera and television tape recorder, provided as part of the general equipment complement.

Activities that can be studied with this technique vary widely, so selection of specific activities will depend on the nature of other crew functions and the general configuration of the various work areas. It is probable that one or more standardized tasks can be selected from the IMBLMS ensemble. Such a set of tasks could range from gross body activities, such as locomotion, exercise, and bicycle ergometry, to rather fine operations, such as manipulation of biochemical equipment or operation of the input keyboard. The setup would require precise positioning of subject and camera to establish a reference system for analysis. It is not anticipated that analysis of the taped records will be performed on board the vehicle because of constraints on the investigator's time, but taped records will be available for review prior to transmittal to ground.

6.6 COMPLEX BEHAVIOR MEASUREMENTS

The range of specific techniques that could be classed as measures of concentration, problem solving, or complex behavior is almost infinite. Therefore, the measurements considered under this category represent functions requiring precise operational definition. Specific measures considered are reaction time, short-term memory, visual pattern perception, and mediational processes. LMSC has selected measures

that have been employed as indices of complex performance in stress or mission-oriented situations and can be precisely defined and related to baseline development data.

6.6.1 Reaction Time

Reaction time represents simply the speed with which an individual is able to respond to a stimulus when it appears. It includes the sense organ activation time, nerve transmission time, central (brain) processing time, and muscle contraction time. Since the latter half of the nineteenth century, reaction time studies have been undertaken, with the general purpose of determining the times required for various psychological processes, in particular central processing time. Generally, these studies showed an increase in reaction time as the number of alternative stimuli was increased. Hick (Ref. 32) first made use of some of these data, as well as his own, to show that reaction time was linearly related to the logarithm of the number of stimuli. In other words, reaction time was a linear function of stimulus uncertainty, an information measure. Reaction time measures, considered in this context, have effectively been used to assess performance changes as a function of various stresses, fatigue, and aging.

Reaction time is used in the complex behavior assembly as an index of the rate at which information is processed. The B.4 approach is the same as that used for B.3. Specifically, reaction time is measured for 1, 2, 4, or 8 alternatives. The single alternative situation is the classical simple reaction time. The 2-, 4-, and 8- alternative situations are choice or disjunctive reaction times. For each alternative situation, there is a block of 120 trials. The block of trials for the single alternative situation is always presented first for each subject. The blocks of trials for the 2-, 4-, and 8- alternative situations are then presented randomly for each subject. The interstimulus interval is randomly varied among durations of 750, 1250, 1750, 2250, 2750, 3250, and 3750 msec.

For the primary mode, the stimuli will consist of visual signals. For the secondary, or backup mode, the stimuli will consist of auditory signals for simple and two-choice reaction times.

6.6.2 Memory Processes

All human information processing requires keeping track of incoming stimuli and bringing such input into contact with already stored material. In the most general sense, short-term memory is the storage capacity available to perform these functions within ongoing serial activity. By measuring some aspect of short-term memory, it is possible to obtain data concerning cognitive processes.

The B.3 approach was to use mental arithmetic, which has been shown to correlate highly with digit span. However, to obtain a purer measure of short-term memory for B.4, the following techniques, which are presently used by researchers in human memory, were evaluated:

(1) Digit span
(2) Memory search (scan)
(3) Probe digit
(4) Missing scan

The memory search technique was selected on the basis of a tradeoff evaluation (Table 6-2). Theoretically this technique involves measurement of the rate at which items stored in short-term memory are scanned rather than the capacity of short-term memory. The assumption is that scan rate will be a more sensitive indicator of the "mental state" of the subject than any measurement of "capacity." However, "capacity" will be measured indirectly in terms of the number of errors made during a testing session.

Table 6-2

TRADEOFF EVALUATION FOR MEMORY PROCESSES MEASUREMENTS

TECHNIQUE:	Digit span
GENERAL PROCEDURE:	String of random digits presented serially to the subject; auditory or visual presentation Warning signal presented after last digit of string Subject recalls digits 1) in the order of presentation, or 2) as many as possible, regardless of the order of presentation Repeat with different strings of digits
VARIABLES:	Number of digits in the string: 4 - 12 digits Rate of presentation: 1 - 4 digits/second
CRITERIA:	Number of digits correctly recalled in order, or Total number of digits correctly recalled as a function of the position of the digits in the string (free recall)
CALCULATIONS:	Mean number correct Variance Serial position curve for free recall
EQUIPMENT:	Device that presents digits serially and randomly Timers to control the rate of presentation Device to encode the subject's responses
BASELINE DATA:	Traditional method of measuring short-term mem memory, with 7 to 9 digits being span for college population at 1 digit/second
ADVANTAGES:	Plentiful baseline data are available Relatively simple to administer and score; suited for automatic administration and scoring Not limited to modality, i.e., technique is suited for auditory or visual presentation

Table 6-2 (Cont.)

DISADVANTAGES:	Process of recalling leads to forgetting; therefore technique doesn't give a measure of whether changes in "capacity" of memory are due to input or output
	Technique requires many sequential responses from the subject, i.e., he must key in all his responses or verbalize his responses so someone else can encode them; therefore, technique is susceptible to motor errors
	Technique is susceptible to subject "cheating", i.e., since digit span is 4-9 digits depending on the rate of presentation (7 digits at 1 digit/second) the subject can develop a strategy of "remembering" only the first few digits of a string regardless of its length and ignore remainder. (This is particularly true with repeated measures.)
CONCLUSIONS:	Not recommended as a technique for assessing short-term
TECHNIQUE	Memory search (scan)
GENERAL PROCEDURE:	String of random digits presented serially to the subject; visual presentation
	Warning signal presented after last digit of string
	Test digit presented
	Subject indicates whether the test digit was "present" or "absent= in the "memorized" list of digits
VARIABLES:	Number of digits in the string: 1 - 5 digits (rate of presentation is approximately 1 digit/second)
CRITERIA:	Reaction time (RT) as a function of the number of digits in the string

Table 6-2 (Cont.)

CALCULATIONS:	Derive equation RT = SN + I, where RT = reaction time S = slope (represents the time required to "process" each additional digit in the string) N = number of digits in the string I = zero-intercept (represents the "motor component" of the reaction time) Tabulate number of errors, false positives and false negatives (however, performance should be relatively error free)
EQUIPMENT:	Same as for digit span, except the device for encoding the subject's response needs to be only two-state, i.e., yes/no, present/absent
BASELINE DATA	Procedure developed as a means of testing parallel versus serial processing of information in memory; results to date generally support serial processing, i.e., RT is a linear function of the number of digits in memory (slope = scan rate = 30 - 50 msec/digit)
ADVANCTAGES	Provides two measures at once: memory scan rate and reaction time (zero-intercept) Suited for automatic administration and scoring Requires one discrete response from the subject on each trial, therefore technique is not susceptible to motor errors Not susceptible to "cheating" since capacity for memory in terms of the number and the rate of inputs is not overloaded Task is somewhat analogous to operational "check list" situations in which an astronaut scans through procedures which have been committed to memory
DISADVANTAGES: than	Requires relatively error free performance, less than 10% error, i.e., items must be encoded and stored in memory; measurement is the scan rate of those items, the assumption being that scan rate is related to the subject's "state." (Although this assumption is highly plausible, no known data exists for support.)

Table 6-2 (Cont.)

CONCLUSIONS:	Recommended technique for assessing short-term memory
TECHNIQUE:	Probe digit
GENERAL PROCEDURE:	String of random digits presented serially to the subject; visual presentation
	Warning signal presented after last digit of string
	"Probe" digit presented
	Subject indicates the digit following the probe
	Repeat with different strings of digits
VARIABLES:	Number of digits in the string: 4 - 9 digits
	Rate of presentation: 1 - 4 digits/second
CRITERIA:	Number correct as a function of the serial position of the "probe" digit
CALCULATIONS:	Mean number correct
	Variance
	Serial position curve
EQUIPMENT:	Same as for digit span
BASELINE DATA:	Procedure developed to minimize interference effects that occur during free recall of digit st strings
	Shape of the serial position curve is similar to that obtained with free recall, i.e., few errors in the first and last positions of the string and many errors in the middle positions
	General shape of the serial position curve varies as a function of any pathology of memory
ADVANTAGES:	Provides for concurrent evaluation of the relative retention of all items in memory
	Suited for automatic administration and scoring

Table 6-2 (Cont.)

	Requires one discrete response from the subject on each trial; therefore technique is not susceptible to motor errors
	Generally not susceptible to "cheating" since the subject does not know the probe
	Task is somewhat analogous to operational "check list" situations in which the astronaut is required to recall sequences in procedures
DISADVANTAGES:	Limited amount of baseline data associating the shape of the serial position curve to any pathology of memory
CONCLUSIONS:	Technique, along with memory search, appears to be the most promising method of assessing short-term memory
TECHNIQUE:	Mission scan
GENERAL PROCEDURE:	String of (X - 1) random digits out of a fixed set of (X) digits presented serially to the subject; visual presentation
	Warning signal presented after last digit of string
	Subject indicates the missing number (the "gap" in the series)
	Repeat with different orders of the set of (X) digits
VARIABLES:	Rate of presentation: 1 - 4 digits/second (number of digits in the set is generally 13)
CRITERIA:	Number correct as a function of the serial position of the "gap"
CALCULATIONS:	Mean number correct
	Variance
	Serial position curve
EQUIPMENT:	Same as for digit span

Table 6-2 (Cont.)

BASELINE DATA:	Procedure developed to minimize interference effects that occur during free recall of digit strings
	Serial position curve in reporting the "gap" is generally a linear increase of "correct" from the first to the last positions
	General shape of the serial position curve varies as a function of any pathology of memory
ADVANTAGES:	Provides for concurrent evaluation of the relative retention of all items in memory
	Suited for automatic administration and scoring
	Requires one discrete response from the subject for each trial; therefore technique is not susceptible to motor errors
	Generally not susceptible to "cheating"
	Some data available with brain damaged patients
DISADVANTAGES:	Technique requires considerable practice and is an extremely difficult task at the higher rates of presentation
CONCLUSIONS:	Note as good as memory search or probe techniques for assessing short-term memory

6.6.3 Visual Pattern Perception

The operator's sensory-perceptual functions are measured with a visual target-identification task, which includes elements of information handling and short-term memory, but not to any highly significant degree. Basically, the operator must examine the apparent similarities and differences between test patterns and a standard pattern or target and judge whether the test patterns are in fact targets.

The B.4 approach is the same as that used for B.3. Specifically, metric figures, a 6 x 6 matrix forming constrained bar graph figures (with only one bar height appearing in each figure), are used. For a given trial, there are three figures: a standard form,

test form 1, and test form 2. The standard form is always presented base down; and the two tests forms are rotated 0, 90, 180, and 270 degrees relative to the standard form. The test sequence is as follows:

(1) Standard form on – 5 sec
off – 2
(2) Test form 1 on – 2
off – 2
(3) Test form 2 on – 2
(4) Response period – 15 (maximum)

The subject responds as follows:

(1) Test form 1 same as standard
(2) Test form 2 same as standard
(3) Both test forms same as standard
(4) Both test forms different from standard

The measure of performance is the number of correct responses for a series of trials.

This task derives from the techniques developed by Alluisi and others (Ref. 4) and has been employed extensively in mission-related investigations of performance. It provides precise control of the nature of the stimuli and can be controlled for level of difficulty.

6.6.4 Mediational Processes

This task provides a specific measure of intellectual functioning, which is typically called "nonverbal mediation." The task is called "COTRAN" (for COde TRANsformation). It was designed to meet the criteria of face validity, sensitivity, engineering feasibility, reliability, flexibility, work-load variability, trainability, and control-data availability.

The procedures for B.4 are the same as those for B.3. Specifically, a problem consist of a three phase sequence:

Phase I – A 5-digit number is presented

Phase II – Another 5-digit number whose sequence is some position transformation of Phase I is presented.

Phase III – The subject derives the above transformation rule and applies it to form a third sequence of numbers.

The measurement of performance is response time and the number of attempts before successful solution.

6.7 SENSORY AND BEHAVIORAL MEASUREMENT PRIORITIES

Measurement priorities were established to serve as a basis for scheduling and establishing measurement frequencies. Prioritizing was accomplished by requiring each of four experimental psychologists working in the sensory and behavioral measurement area to rank order the measures under each measurement category (visual, auditory, etc.). Ranking was performed individually after an extended group discussion, which clarified the nature, significance, and probable sensitivity of the measure. The basic groundrule was to select measures that were expected to be most sensitive to potential changes. The rank orders within measurements assemblies are shown in Table 6-3.

Subsequent to ranking by measurement assemblies, members of the group were asked to select the 10 most important measures from the entire battery on the basis of composite criteria of sensitivity to potential changes and range of functions covered (Table 6-4). The results of these two ranking procedures were compared.

If a measure appeared in the top 10 for 1, 2, or 3 of the raters, but not for all four, it was assigned the following rankings:

(1) 11 for measures receiving votes from three panel members
(2) 12 for measures receiving votes from two panel members
(3) 13 for measures receiving votes from one panel member

The ranks for each measure were summed, and the top 10 measures were again ranked. The results of these rankings are shown in Table 6-5.

Table 6-3

RANK ORDER OF SENSORY AND BEHAVIORAL MEASUREMENTS WITHIN MEASUREMENT CLASS

Measurement	Rater				Σ	Rank
	1	2	3	4		
CFF	3	1	1	1	6	1
Acuity	1	3	4	3	11	2
Dark adaptation	4	2	2	4	12	3
Phorias	2	5	5	2	14	4
Brightness	8	4	3	8	23	5
Visual field	5	7	6	7	25	6.5
Color	6	6	8	5	25	6.5
Depth perception	7	8	9	6	30	8
Photo stress	9	9	7	9	34	9
Absolute threshold	1	3	1	1	6	1
SISI	3	2	3	3	11	2.5
Pitch discrimination	4	1	2	4	11	2.5
Speech intelligibility	2	4	4	2	12	4
Temporal acuity	5	5	5	5	20	5
Touch threshold	1	1	1	1	4	1
2-point threshold	2	2	2	2	8	2
Vibratory	3	3	3	3	12	3
VTHR	NO VOTE	NO VOTE	1	1	2	1
MSS			2	2	4	2
Agravic perception			3	3	6	3
OGI			4	4	8	4
Ocular counterrolling			5	5	10	5
AAT			6	6	12	6

Table 6-3 (Cont.)

Measurement	Rater				Σ	Rank
	1	2	3	4		
Tracking	1	1	1	1	4	1
Fine motor	2	2	2	2	8	2
Memory	3	4	3	4	14	3
RT – visual	4	5	4	3	16	4
Pattern perception	5	6	6	5	22	5.5
Complex motor	7	3	5	7	22	5.5
Mediation	6	7	7	6	26	7
RT – auditory	8	8	8	8	32	8

Table 6-4

TOP TEN CHOICES OF EACH MEMBER OF PANEL

Rank	Rater			
	1	2	3	4
1	Tracking	CFF	CFF	Tracking
2	Acuity	Auditory absolute	Tracking	CFF
3	Auditory absolute	Fine motor	VTHR	VTHR
4	Fine motor	Tracking	Fine motor	Fine motor
5	Phorias	Memory	Acuity	Memory
6	Speech	Acuity	Agravic	Dark adaption
7	Memory	Touch	Auditory absolute	Auditory absolute
8	CFF	VTHR	Dark adaption	Speech
9	SISI	Dark adaption	OGI	RT – visual
10	Depth perception	SISI	Memory	Acuity

Table 6-5

COMBINED RANKS OF OVERALL AND PIECEMEAL RANKING

Measure	Measurement Class
Tracking	Psychomotor
CFF	Vision
Fine motor	Psychomotor
Auditory absolute threshold	Audition
Acuity	Vision
VTHR	Vestibular
Memory	Complex behavior
Dark adaption	Vision
Speech intelligibility	Audition
SISI	Audition

The measures that ranked high on both the subassembly and overall ranking, those that ranked high only within a measurement subassembly, and those appearing only on the overall rankings are shown in Table 6-6.

Table 6-6
SUMMARY OF RATING RESULTS

Common to Both Lists	Appearing Only Within Groups	Only on Overall List
Tracking	Touch threshold	Memory
CFF	Two-point threshold	Dark adaption
Fine motor	MSS	Speech intelligibility
Auditory absolute threshold		
Visual acuity		
VTHR		
SISI		

In summary, it can be seen that there is relative consistency among the four panel members in their choice of measurements, based upon the three criteria. Also, there is consistency between the "piece meal" and the overall ranking procedures.

Section 7
ENVIRONMENTAL MEASUREMENTS

Environmental monitoring is important because various physiological parameters can be affected by the physical environment in which the subject is or has been located. In the natural and induced environment of the Space Station (i.e., zero-g, increased background radiation levels, artificial atmosphere, etc.) it is even more important to know precisely the value of the different environmental parameters that may affect the medical, behavioral, and biochemical measurements of the subject.

Some of the interrelationships between environmental conditions and physiological measurements are summarized as follows:

(1) Ambient pressure and temperature affect conversion of certain respiratory measurements to STP and may affect blood gas determinations.

(2) Ambient atmosphere composition affects respiratory measurements during oxygen consumption (carbon dioxide production measurements) if the subject inspires ambient air.

(3) Ambient temperature and humidity affect a subject's performance under streneous exercise and during behavioral tests.

(4) Spacecraft motion can affect certain vestibular measurements by giving cues to the subject and can distort a ballistocardiogram record by superimposed accelerations.

(5) Noise would interfere with audiometry, may provide cues during vestibular tests, and can distract the subject who is performing behavioral measurements requiring intense concentration.

(6) High levels of background radiation, toxic, particulate, and bacterial contaminants endanger the astronauts' general well being. Exposure to the last three may influence respiratory measurements before any overt signs of disease become evident.

From the above, it is clear that certain environmental parameters must be measured periodically as close as possible to the subject's head or body. This requirement makes it necessary that certain sensors of the environmental monitoring system be positioned very close to the subject. These include the sensors required to measure

temperature, humidity, and spacecraft acceleration and noise, as well as the sampling port for space cabin atmosphere analysis.

The accuracy of the sensing elements and the associated electronics of the environmental monitor must be sufficient to provide meaningful correction factors for physiological parameters to which these corrections have to be applied in order to avoid degrading instead of augmenting the accuracy of these physiological measurements.

Although the Space Station's environmental control and life support subsystem (ECLSS) includes the capability for monitoring and controlling most of the IMBLMS-relevant parameters, the accuracy requirements for the ECLSS generally are below what is needed for the correction of physiological measurements. The relatively large distance between the IMBLMS area and the ECLSS sensors would, in specific cases, render the readouts obtained by the latter all but useless for the above purpose. For instance, because of the absence of gravity and the relatively slow circulation rate of the ECLSS, CO_2 levels in the atmosphere immediately surrounding the subject performing on the bicycle ergometer could build up to significant levels and at a much reduced value due to dilution long before the ECLSS would measure this increase in the total atmosphere. To convert spacecraft motion, measured at some central location, into actual acceleration levels in the three axes at the level of the subject's head during rotation on the RLC and on a continuous basis would require an extremely complex computer program.

The details of the environmental measurement requirements are contained in Appendix B.

Section 8
MEDICAL HISTORY AND PHYSICAL EXAMINATION

The astronauts' medical history will be available to the onboard physician, either in the form of a copy of each individual's MEDATA tape, which is carried onboard as part of the medical inventory, or specific data called up from ground control upon demand. The latter method is preferred by LMSC, since this allows full use of MEDATA's specialized file and search system capability, which would be costly to duplicate onboard the Space Station.

The clinical questionnaire will provide an across-the-board evaluation of the mental as well as the physical status of the crew members. Emphasis will be placed on the particular phenomena that are considered to be spaceflight-specific and likely to occur during prolonged flights. Many abnormal or disease states with low probability of occurrence in healthy subjects are not included in this questionnaire. Should it become necessary to include additional remarks or observations, the onboard physician will record these on a voice channel for direct or delayed transmission to ground control. A special code number is used to indicate that such additional observations are included.

Measurements of vital signs, per se, which are taken very frequently as part of the routine monitoring with the IMBLMS measurement equipment, will not be included, although these can be verified manually whenever necessary.

The general status of the astronaut and the results of his physical examination are combined in a single format, with a logical progression from general to more specific information, consistent with the classical physician's review of the body systems. Details of this format are given in Volume IV, Section 3.

Section 9
NEW MEASUREMENTS

In addition to fulfilling the specified NASA requirements, as discussed in preceding sections of this volume, IMBLMS must have the capability of integrating crew measurements that might reasonably be conceived. Two such measurement groups are discussed in this section.

9.1 URINARY ENDOCRINE ASSAY

The IMBLMS B.4 preliminary flight design can accommodate a urinary endocrine assay experiment, which requires the collection of 24-hour aliquots of urine for subsequent post-flight analysis. Similar capability in terms of labeling and storage is required for the IMBLMS mineral balance studies. Developmental studies should be performed to determine the stability of para-thyroid hormone and ACTH under IMBLMS freezing preservation technique conditions. If preservation agents are required, their effect on other parameters of interest for related experiments should be identified. In summary, the urine endocrine assay experiment would place only the following minimal additional requirements on the IMBLMS B.4 design:

(1) The specific labeling and possible addition of a specific preservation agent to 24-hour urine aliquots if incompatibility exists in preserving urine for other post-flight measurements

(2) Increase preservation freezing capacity, depending on the compatibility with the standard IMBLMS preservation technique and the frequency and number of aliquots required to perform the experiment

9.2 ENDOGENOUS CO PRODUCTION

The endogenous CO production experiment requires measurement of the CO in the exhaled breath as an indication of the rate per heme degradation; and, following the ingestion of C^{14} glycine, the rate of $C^{14}O^{16}$ in the exhaled breath must be measured to determine the rate of synthesis of heme and the red-cell life span. This experiment requires the use of a sensitive infrared analyzer to measure CO and modifications

to the IMBLMS pulmonary system to permit sampling of the expired breath by the CO analyzer. (If available, the CO analyzer could be used for the IMBLMS diffusion capacity measurement.) In addition, to measure $C^{14}O^{16}$, a lithium hydroxide scrubber to remove possible $C^{14}O_2^{16}$ interference and a gas flow ionization chamber would be connected to the exit port of the IMBLMS expiratory spirometer. Appropriate applications software would be required to control the experiment and perform the necessary calculations to derive the data. The IMBLMS B.4 preliminary design provides for the detection by the mass spectrometer of $C^{12}O^{18}$ in conducting the diffusion capacity measurement. $C^{14}O^{16}$, which has the same atomic mass as $C^{12}O^{18}$, could be detected by the IMBLMS mass spectrometer. However, the sensitivity of the mass spectrometer would probably be inadequate for the expected concentrations of exhaled $C^{14}O^{16}$. In summary, the endogenous CO production experiment places these additional equipment and software requirements on the IMBLMS B.4 design:

(1) CO infrared analyzer
(2) Lithium hydroxide scrubber
(3) Gas flow ionization chamber
(4) Plumbing modifications to the pulmonary system
(5) Applications software

REFERENCES

1. Acoustical Society of America, "American Standard Criteria for Background Noise in Audiometer Rooms," 53.1, 1960

2. Acoustical Society of America, "American Standard Method for the Measurement of the Real-Ear Attenuation of Ear Protectors at Threshold," Z24.22 1957

3. Alluisi, E. A., "Methodology in the Use of Synthetic Tasks to Assess Complex Performance," Human Factors, 9, 1967, 375-384

4. Alluisi, E.A., G. R. Hawkes and T. J. Hall, ,The Filtering of Visual Noise in a Form Perception Task Under Two Levels of Multiple-Task Performance, LAC ER 6142, April 1963

5. Alluisi, E. A., and B. B. Morgan, Jr., Effects of Practice and Work Load on the Performance of a Code Transformation Task (COTRAN). NASA CR-1261, December 1968a.

6. Alluisi, E. A., J. B. Thurmond, and G.D. Coates, Behavioral Effects of Infectious Diseases: Respiratory 'Pasteurella Tularensis" in man. ITR-67-6, February 1967b.

7. APL S4M-0-162, "Report on Skylab Experiment M131, Configuration Specification, Section II Flight Hardware," 7 Jul 1970

8. Baker, C. H., and R. J. Hall, "Cutaneous Sensitivity: A Review of the Literature, Problems, and Approaches," U.S. Army Tech Memo 21-69, U.S. Army Human Engineering Laboratories, Dec 1969

9. Bauer, B., A. Rosenbeck and L. Abbagnaro, "External Ear Replica for Acoustical Testing," J Acoust Soc Amer, 42, 1967, 204-207

10. Beasley, W.E., National Health Survey, Hearing Study Series, Bulletin 5, U.S. Public Health Service, 1938

11. Bevan, W., R. A. Bell and C. Taylor, "Changes in Response Latency Following Shifts in the Pitch of a Signal. J of Exp Psych, 72, 1966, 864-868

12. Bilger, R. C., and R. W. Conn, "A Simplified Adaptive Psychophysical Procedure," unpublished document, personal communication with Rufus L. Grason

13. Bilodeau, E. A., ed, Acquision of Skill, New York, Academic Press, 1966, "Tracking Behavior," E. C. Poulten; "Comments on Dr. Poulten's Paper," G. E. Briggs

14. Buschke, H. and H. Lim, "Temporal and Interactional Effects in Short-Term Storage, Percep and Psychophys, 2(3), 1967, 107-114

15. Campbell, R. A., "Detection of a Noise Signal of Varying Duration," J Acous Soc Amer, 35, 1963, 1732-1737

16. Chiles, W. D., E. A. Alluisi, and O. S. Adams, "Work Schedules and Performance During Confinement," Human Factors, 10, 1968, 143-196

17. Clark, B., "Comparison of Sensitivity for the Perception of Bodily Rotation and the Oculogyral Illusion," Percep and Psych, 3, 1968, 253-256

18. Clark, B., "Comparison of Three Methods to Determine Thresholds for Perception of Angular Acceleration," Am J of Psych, 81, 1968, 207-216

19. Clark, B., "Thresholds for the Perception of Angular Acceleration in Man," Aerospace Med, 38, 1967, 443-450

20. Clark, B., and J. D. Stewart, "Effects of Angular Acceleration on Man: Thresholds for the Perception of Rotation and the Oculogyral Illusion," Aerospace Med, 40, 1969, 952-956

21. Cornsweet, T. N., "The Staircase Method in Psychophysics," Am J Psyc, 75, 1962, 485-491

22. CSD A116, "Definitive Experiment Plan for Apollo Inflight Human Otolith Function Experiment M009 (M9A), 23 Nov 1965

23. Elfner, L. F. and J. L. Homick, "Some Factors Affecting the Perception of Continuity in Alternately Sounded Tone and Noise Signals," J Acous Soc Amer., 40, 1, 1966, 27-31

24. Elfner, L. F., "Continuity Effects With Alternately Sounding Tones Under Dichotic Presentation," Percep and Psychophys, 2, (1), 1967, 34-36

25. Elfner, L. F., "Auditory Continuity Effects as a function of the Duration and Temporal Location of the Interpolated Signal," J Acous Soc Amer, 42, 3, 1967, 576-579

26. Garner, W. R., Uncertainty and Structure as Psychological Concepts, New York, John Wiley, 1962

27. Graybiel, A., "Structural Elements in the Concept of Motion Sickness," Aerospace Med, 40, 1969, 351-367

28. Graybiel, A., et al, "Diagnostic Crtieria for Grading the Severity of Acute Motion Sickness," Aerospace Med, 39, 1968, 453-455

29. Graybiel, A., et al, "Vestibular Experiments in Gemini Flights V and VII," Aerospace Med, 38, 1967, 360-370

30. Grier, J. B., "Auditory Reaction Time As a Function of Stimulus Intensity and Rise Time, Psychonomic Sci, 6, 1966, 307-308

31. Harris, J. D., "Pitch Discrimination," J Acous Soc Amer, 24, 1952, 750-755

32. Hick, W. E., "On the Rate of Gain of Information," Quar of Exp Psych, 4, 1952, 11-26

33. Jerger, J., "Hearing Tests in Otologic Diagnosis," Amer Speech Hear Assoc, 4, 1962, 139-145

34. Kenshalo, D. R., ed, The Skin Senses, C. C. Thomas, Springfield, Ill, 1968

35. Koster, W. G., ed, "Attention and Performance II," Acta Psychologia, 30, 1969

36. Madsen, M. C., and J. M. Drucker, "Immediate Memory by Missing Scan and Modified Digit Span," Psychonomic Sci, 6(6), 1966, 283-284

37. Miller, E. F., II, "Evaluation of Otolith Organ Function by Means of Ocular Counterrolling Measurements," NAMI-1063, Mar 1969

38. Miller, E. F., II, "Visual Localization of the Horizontal As a Function of Body Tilt Up to ±90 Degrees From Gravitational Vertical, NSAM-942, August 1965

39. Miller, E. F., et al, "Motion Sickness Susceptibility Under Weightless and Hypergravity Conditions Generated by Parabolic Flight," Aerospace Med, 40, 1969, 862-868

40. Miller, E. F., et al, "Otholith Organ Activity Within Earth Standard, One-Half Standard and Zero Gravity Environments," Aerospace Med, 37, 1966, 399-403

41. Miller, E. F., et al, "Visual Horizontal-Perception in Relation to Otholith Function," Am J of Psych, 81, 1968, 488-496

42. Miller, G. A. and W. G. Taylor, "The Perception of Repeated Bursts of Noise," J Acous Soc Amer, 20, 1948, 171-182

43. MSC-KW-E-69-19A, 'End Item Specification Flight Hardware for Human Vestibular Function (Experiment M131)," 12 Dec 1968 (revised 13 Jun 1969)

44. Murdock, B. B., "Auditory and Visual Stores in Short-Term Memory," in Attention and Performance, Sanders, A. F. ed, Amsterdam, North Holland Publishing Co., 1967

45. Murray, H. G., and D. L. Kohfeld, "Role of Adaptation Level in Stimulus Intensity Dynamism, Psychonomic Sci, 3, 1965, 439-440

46. NASA-DV-56-67-M131, 'Experiment Implementation Plan for Experiment M131 Human Vistibular Function," 1 Aug 1967

47. NASA-M-053 C-1-AAP, "Human Vestibular Function"

48. Oosterveld, W. J., "Threshold Value for Stimulation of the Horizontal Semi-Circular Canals," Aerospace Med, 41, 1970, 386-389

49. Passey, G. E., E. A. Alluisi, and W. D. Chiles, "Use of the Experimental Method for Evaluations of Performance in Multi-Man Systems," LAC 5, October 1963

50. Pollock, I., "Detection and Relative Discrimination of Auditory Jitter," J Acous Soc Amer, 43, 1968, 308-315

51. Pollock, I., 'Differential Asynchrony Thresholds for Auditory Pulse Trains," J Acous Soc Amer, 45, 1968, 446-449

52. Pollock, I., 'Discrimination of Mean Temporal Interval Within Jittered Auditory Pulse Trains," J Acous Soc Amer, 43, 1968, 1107-1112

53. Roman, J. W., et al, "The Function of the Semicircular Canals During Weightlessness," Aerospace Med, 34, 1963, 1085-1089

54. Shaw, E. A. G., "Earcanal Pressure Generated by Circumaural and Supraaural Earphones," J Acous Soc Amer, 39, 1966, 471-479

55. Shaw, E. A. G., "On the Calibration of Audiometric Earphones, "National Research Council of Canada, Division of Applied Physics, 1968

56. Shower, E. G., and R. Biddulph, "Differential Pitch Sensitivity of the Ear," J Acous Soc Amer, 3, 1931 275-287

57. Silvian, L. J. and S. D. White, "On Minimum Audible Sound Fields, J Acous Soc Amer, 4, 1933, 288-321

58. Simon, J. R., "Choice Reaction Time As a Function of Auditory S-R Correspondence, Age and Sex," Ergonomics, 1967, 10, 659-664

59. Speaks, C. and J. Jerger, "Synthetic Sentence Identification and the Receiver Operating Characteristics," J. Speech Hear Res, 1967, 10

60. Sternberg, S., Memory-scanning: Mental processes revealed by reaction time experiments. American Scientist, 1969, 57(4), 421-457

61. Taylor, M. M., and C. D. Creelman, "PEST: Efficient Estimates on Probability Functions," J Acous Soc Amer, 41, 1967, 782-787

62. Thurmond, J. B., E. A. Alluisi, and G. D. Coates, "An Extended Study of the Behavioral Effects of Respiratory 'Pasteurella Tularensis' in Man," ITR-68-8, February 1968

63. Tursky, B., and D. N. O'Connell, "A Comparison of AC and DC Eye Movement Recording," Psychophysiology, 3, 1966, 157-163

64. Verillo, R. T., "The Effect of Number of Pulses on Vibrotactile Thresholds," Psychonomic Sci, 3, 1965, 73-74

65. Verillo, R. T., "Tactile Thresholds for Short Pulses," Psychonomic Sci, 4, 1966, 409-410

66. Verillo, R. T., "Vibrotactile Threshold and Pulse Polarity," Psychonomic Sci, 3, 1965, 171

67. Whimbey, A., V. Fischof, and R. Silikowitz, "Memory Span: A Forgotten Capacity," J of Edu Psych, 60, 1969, 56-58

68. Woodworth, R. S., and H. Schlosberg, "Exp Psych," revised ed, New York, Harold Holt and Co., 1954

69. Wright, H. N., "Switching Transients and Threshold Determination," J Speech Hear Res, 1958, 1

70. Wright, H. N., "An Artifact in the Measurement of Temporal Summation at the Threshold of Audibility," J Speech Hear Dis, 1967, 32

71. Wright, H. N., "Clinical Measurement of Temporal Auditory Summation," J Speech Hear Res, 11, 1968

72. Wright, H. N., "The Effect of Sensori-Neural Hearing Loss on Threshold Duration Functions," J Speech Hear Res, 11, 1968

73. Wright, H. N., "The Problem of Measuring Temporal Summation in the Hearing Impaired Patient," Internat Audiology, 5, 1967, 415-422